Fuzzy Logic Based Selection of Machining Parameters

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FUZZY LOGIC BASED SELECTION OF MACHINING PARAMETERS

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To

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by

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DECLARATION

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Master of Science is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledge within the text of my work

Signed Kashmeri Hashmi ID No 94970696

Date ______________________

ABSTRACT

Selecting cutting parameters for machining is a complex problem A fuzzy logic based approach to setting these parameters is developed and implemented The materials data used were for medium carbon leaded steel (BHN 125-425) and freemachining carbon wrought steel (BHN 225-425) Three different depths of cut (1mm, 4mm and 8mm) and four types of tools were used for the study, i) High Speed Steel Tool, ii) Carbide Tool-Coated, iii) Carbide Tool-Uncoated Brazed and iv) Carbide Tool-Uncoated indexable

The data used to evaluate the fuzzy model were taken from the Machinability Hand Book [99] which contains the most appropriate values and ranges used for different types of materials in the industrial environment

Two fuzzy models were developed for carrying out these calculations In fuzzy model- 1, the fuzzy metric arcs are overlapped at 50% and in fuzzy model- 2, the fuzzymetric arcs are overlapped at 33%

Computer software was developed to implement the model and to predict the cutting conditions for the two materials mentioned above The results based on the initial models were improved by tuning the models further The results were then in excellent agreement with the machinability hand book The programme as it stands is applicable for Medium carbon leaded steel and Freemachining carbon wrought steel only However, it could be extended to incorporate different work materials and tool combinations once appropriate data is available

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TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

Machinery has become indispensable to the modern world Today, machine tools form the basis of our industry and are used directly or indirectly in the manufacture of all the products of modern civilisation Whatever metal is used in any-man-made object, it must have reached its final stage through processing with machine tools Even parts made from plastics require metal dies made with machine tools

The origins of the machine tool industry can be traced to the early days of stone age, when men first learned to make round holes in stones using their hands to rotate a wooden stick pressing sand against the surface being worked upon The history of bow driven turning lathes, for making wooden ornaments, has been traced as far back as 5000 B C In 1568, a lathe using a pedal and wooden spring and a tool rest was in use for making things like plates, flasks, wind instruments etc In the seventeenth century[1], specialised turning shops producing only wooden dishware were on the scene In the eighteenth century people used water power and horse power for driving lathes in the production of highly complicated articles such as vases, tables, snuff boxes etc The cutting conditions were set by the individuals based on years of experience

Machines were made by skilled craftsman over a number of years But the requirements of mass production resulting from the industrial revolution made it necessary to create machines in order to produce machines Consequently the developments in machine tool technology became much faster The most rapid growth of the machine tool industry and technology has occurred in the twentieth century

The traditional machining operations include turning, boring, drilling, milling, grinding etc The principle used in all machine tools is one of generating the surface required by providing suitable relative motions between the cutting tool and the workpiece In machine tool operation two vital concerns of the manufacturing

[1] Juneja, B L and Sekhon, G S , "Fundamentals of Metal Cutting and Machine Tools", John Wiley & Sons, 1987

engineer are production costs and production rates In practice, a high production rate would probably mean low production cost, but the manufacturing conditions giving the maximum production rate is generally not identical to those giving the minimum cost of production

In general the production of a component will involve several machining operations using a variety of machine tools Given the appropriate tool and cutting fluid, the cutting conditions to be determined are the cutting speed, the feed rate and the depth of cut In any operation, when either the cutting speed or feed rate are increased while the other condition is held constant, the actual machining time will be reduced and the tool-wear rate will increase Very low speeds and feeds will result in a high production cost because of the cost of using the machine and operator for the long machining time Alternatively, very high speeds and feeds may also result in a high production time because of the frequent need to change cutting tools, and cost may be high because of the cost of frequent tool replacement How to minimise both the production time and production cost is the manufacturing engineer's biggest problem However, experience gained over the years by the skilled operator has led to certain empirical rules or guiding principles for choosing the optimum cutting conditions for a given machining operation

Many researchers in this regard have suggested a machinability data system which will provide information needed for the automatic selection of machining data The purpose of the data system is to generate the recommended cutting speed, feed rate, and depth of cut for different cutting tools Systematic collection and storage of large quantities of data from laboratory and industry has resulted in the so called "Machinability hand book" which provides recommended cutting speeds, feed rates, and depths of cut for any specific cutting tool Data from industry are reliable in the sense that it has been used successfully in practice Workpiece materials are grouped according to their material Brinell Hardness Number (BHN) Using the machining hand book for choosing cutting conditions for material hardness that lies at the middle of the group is simple and straight forward But there exists a degree of vagueness for the boundary cases, where two choices of cutting speeds are applicable for one choice of material hardness In this situation, the skilled operator decides the appropriate cutting speed based on years of experience However this method of choosing data by the individual operator is not desirable, because it may vary from operator to operator It is desirable to have an operator independent system for consistent machining operation

The main objectives of the present research are -

1 - To investigate the application of fuzzy logic for machining data selection

2 - To develop fuzzy models for machining medium carbon leaded steel and free machining carbon wrought steel

3 - To develop a computer system based on the principles of fuzzy logic for automatic selection of machining parameters

The work programme of this project is outlined in the following diagram method of choosing data by the individual operator is not desirable, because it may vary from operator to operator It is desirable to have an operator independent system for consistent machining operation

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The work programme of this project is outlined in the following diagram

Application of fuzzy logic for machining data selection

work-material	medium carbon leaded Steel (125-425) BHN	free machining carbon-wrought Steel (225 - 425) BHN
Theoretical Investigation		
- Cutting Tool	high speed steel carbide tool coated carbide tool uncoated brazed carbide tool uncoated indexable	high speed steel carbide tool coated carbide tool uncoated brazed carbide tool uncoated indexable
- Depths of cut	1mm, 4mm, 8mm	1mm, 4mm, 8mm
Application of fuzzy model	model 1-fuzzy sets overlapped by 50% model -2 fuzzy sets overlapped by 33%	model-1, fuzzy sets overlapped by 50%
Software development	automatic data selection	automatic data selection

Output (Recommended cutting conditions)

Chapter 2 1 gives a literature survey covering the general background to fuzzy logic theory and discusses it in comparison to traditional set theory It also provides a literature survey of the application of fuzzy logic in the following four main areas i) control systems, ii) robotic guidance, iii) industrial appliances, and iv) medical diagnosis

Chapter 2 2 gives a general discussion on machinability assessment and the factors affecting machinability The machinability parameters i e surface roughness, cutting speed, tool life and depths of cut generally investigated in the machinability of a material are discussed Also, the different cutting tools and their application in relation to turning of high and medium strength material are discussed

Chapter 3 presents a general discussion on fuzzy logic theory Traditional set operations and fuzzy set operations are also presented The difference between crisp sets and fuzzy sets and difference types of membership functions are also discussed The fuzzy rules and the basis on which they are made and the procedure to establish fuzzy relations are also illustrated The various steps needed to build a fuzzy control system are presented The concept of fuzzy membership functions and how the different functions affect the finer control of the system are also discussed

Chapter 4 presents an overall discussion on machinability of a material A brief discussion on the formation of different types of chips, cutting conditions, cutting tool geometry, workpiece geometry, workpiece materials and tool material is included The effect of machining parameters on surface finish and how the cutting fluid acts as coolant as well as reducing tool wear are also discussed

Chapter 5 presents the development of two fuzzy models for selecting the cutting conditions in machining operations The work materials used for the theoretical calculations are presented The cutting tool materials and tool geometry are also described Membership functions that have been chosen for the machining operation and the step by step development of the fuzzy relation between the material hardness (BHN) and the cutting speed are described The results of the calculations obtained for four types of tools at three different depths of cut using both fuzzy models are also presented and discussed

Chapter 6 presents the fuzzy logic simulation program that has been developed for selecting cutting conditions in machining operations A brief description about the program and how to use it is also presented

Finally, conclusions and recommendations for further work are discussed in Chapter 7

CHAPTER 2 LITERATURE SURVEY

2.1. Literature Survey of Fuzzy Logic

2.1.1 Introduction

Fuzzy set theory was developed in 1965 by Lotfi Zadeh [1] of the University of California at Berkeley. Most of the traditional tools for formal modelling, reasoning and computing are crisp, deterministic and precise in character. By crisp is meant that attributes are of the 'yes' or 'no' rather than the 'more' or 'less' type. In conventional logic, for instance, a statement can be true or false, but not in between. An element is a member of a certain set or not. The binary logic used in traditional set theory has proved very effective and successful in solving many well defined problem, where descriptions of the process is being dealt with in quantitative form. But real situations are very often not crisp and deterministic and cannot be described precisely. Fuzzy set theory can be viewed as one approach to deal with these kind of problems. L. Zadeh [1] introduced fuzzy sets as an extension to traditional set theory and also developed the corresponding fuzzy logic to manipulate them. Lack of crispness is an aspect of many real world properties, and fuzzy logic allows us to define the linguistic terms to name these properties. Over the past few decades, fuzzy logic technology has been successfully applied in many industrial control applications, especially since dedicated fuzzy logic processors started becoming available in the 1980's. The framework provided by fuzzy sets is perhaps the most natural and accurate currently available for dealing with non-crisp properties. Its major advantage is that it allows the description of a system and its desired performance in linguistic terms rather than in terms of relationships between precise numerical values. Since about 1985 there has been a strong growth in its use for dealing with problems of control, particularly in non-linear, ill-defined, time-varying and complex situations. Various hardware products aimed at speeding up the computations involved have appeared on the market. As a result, fuzzy logic based control has boomed and has been applied in many areas, including subway operations, automobile transmissions, object tracking, camcorder focusing, TV colour tuning, washing machine automation, robot guidance, image processing, character recognition and so on.

Application of fuzzy logic theory in the following four areas are described below.

1. Application of fuzzy logic in control system
2. Application of fuzzy logic in robotic guidance
3. Application of fuzzy logic in industrial appliances
4. Application of fuzzy logic in medical diagnosis

2.1.2 Application of Fuzzy Logic in Control System.

More than 2 decades ago, Professor L. A. Zadeh [1] of the University of California published the first paper on fuzzy set theory. In 1980, about a dozen years later, Smith Corp. in Denmark produced a fuzzy controller for a cement kiln. Subsequently, many other developers in Japan and elsewhere constructed controllers on an experimental basis, and now the concept enjoys widespread recognition for its usefulness. Fuzzy logic is increasingly being incorporated in systems to provide robust and effective control in a wide range of applications.

Sukvittayawong and Inasaki [2] have proposed a system for identifying chip form in turning processes in an unmanned situation. Fuzzy set theory and neural networks are applied to identify the chip form. The results of the interaction between workpiece, tool and machine tool are continuously monitored so that any change in the turning environment can be sensed in order to take corrective action. The system also used acoustic emission signal analysis to identify the chip form during cutting. In experiments the percentage of correct identification of chip form using both the methods is always higher than 90%.

Lewis, [3] presented a paper in 1994 where he described the implementation of fuzzy logic (FL) as a new technique based on microprocessor capabilities that enables control devices to 'think' more like humans. This capability helps to automate systems that previously required constant monitoring and intervention. He also expressed the view that since FL uses English syntax programming, it reduces the size of software programs and lets engineers develop control system in as little as 1/10 the time of conventional methods.

Wang and Birdwell, [4] have developed a new fuzzy - PID controller, which merged PID control and fuzzy control in order to improve system performance especially when uncertainty and complexity are involved The proposed model provided a mechanism to achieve PID controller selftuning and encoded different control strategies for use under different circumstances in fuzzy rulebases It has been suggested that the derived controller can always equal or better the performance of any PID controller The new structure was implemented for several plants and demonstrated significant improvements in system performance

Wang et al [5] have developed a fuzzy tracking system for rotation-invariant image tracking A dual template strategy was proposed and only two parallel matched filters and a simple fuzzy logic system were employed to construct the novel fuzzy tracking system The experiments showed that the system can track the target more accurately and rapidly and also less expensively than the conventional rotation-invariant methods

DeCorte et al [6] reported that Cybermotion Inc has proved that the idea of dual-use technology worked with their security robot the SR2 Due to the decreasing overhead and since increasing security is always beneficial for both government and the commercial world, this has led to the development of an autonomous security robot equipped with a fuzzy logic certainty system This robot with its fuzzy logic system can furnish a significant and cost-effective safety function

Dhawan, [7] et al have developed a expert-fuzzy system called COGSA (core geometry selection aid), which is a combination of expert system and fuzzy logic techniques for selecting optimum core geometry and core size for high frequency power transformers COGSA aids the magnetic designer in the selection of a core geometry, taking into account various decision components such as power, cost, heating and shielding in the form of IF-THEN statements Fuzzy rules were manipulated by a forward chaining method and fuzzy logic was applied to consider the uncertainty involved with the various factors. COGSA operates under the Microsoft windows operating system, gathering inputs from the user and then processes these inputs and displays the final output both numerically and in a graphical form

Xiong and Holditch, [8] carried out an investigation into the application of fuzzy logic to oil and gas well stimulation treatment design It has been concluded that fuzzy logic theory can be used to build evaluators to help an engineer to select the optimal stimulation

Gondo et al [9] have installed a paired crossed roll mill in no 1 Hot Strip Mill in NKK Fukuyama works in Japan in order to control hot strip crown and flatness effectively Mathematical models were developed using fuzzy logic and have been applied to an on-line process control computer system They have reported that strip crown can be controlled accurately with this new fuzzy control system

Wong et al [10] have incorporated a series of fuzzy logic based algorithms for recognition and classification of the defects on high integrity casting surfaces Fuzzy logic memberships were generated for the detection of defects found on casting surfaces Simulated model shapes of quench cracks and mechanical cracks were used to test the generated algorithm Results for recognition and classification were very encouraging and they obtained very good results

2.1.3 Application of fuzzy logic in Robotics Guidance.

The Application of fuzzy logic to robotics was first conducted by Uragami et al [11] in 1976 The robot controls were based on fuzzy programs The fuzzy program [11] were defined as an ordered sequence of fuzzy instructions In the fuzzy program, fuzzy instructions are translated into machine instructions by the use of max-method and back-tracking

Similar work on robots was also reported by Goguan [12] Fuzzy linguistic hints were used to aid a robot running through a maze

In 1985 a robot with a knowledge base of movement was studied by Hirota et al [13] The knowledge base is mainly composed of control rules in terms of probabilistic sets in extended fuzzy expressions The ambiguous instructions in terms of membership and vagueness are given to the robot and then the robot is able to recognise these instructions and select an appropriate movement

Also in 1985, Scharf et al, [14] presented a fuzzy self organising controller (SOC) for a robot arm The SOC consists of the rule base, the performance matrix, rule reinforcement and the history buffer Experiment shows that the performance of the SOC is superior to a conventional PID controller Further work on the SOC based on fuzzy logic was carried out by Tanschett and Scharf [15] In the improved SOC, the input signals, which are mapped to one of 13 discrete levels, are processed by using the rule-based control algorithm The output signals, in a linguistic form, are mapped to a real value

In 1991 Kouatle and Jones [16] developed a fuzzy controller for a robot welding system The objective was to control the speed of the robot arm to carry out the welding process in the same manner as the human welding operator A scale for partitioning the universe of discourse was determined by using the expert's knowledge The fuzzy reasoning was based on a compositional rule of inference The speed of the robot arm controlled by the fuzzy logic controller varies with the cavity size of the workpiece being welded

Saridis [17-19] has used a fuzzy logic based controller to construct linguistic decision modules for intelligent robots The intelligent fuzzy logic controllers proposed by Ray et al [20] have potential impact on future intelligent robots As suggested in [20], under normal operating conditions the controller will receive information from regular observations of plant data and select a suitable control strategy using the compositional rule of inference Under abnormal conditions, normal control actions are modified using a knowledge based decision theoretic scheme

Chen and Tsao [21] have carried out the global analysis of fuzzy dynamical systems By using this method, approximate prediction of the behaviour of a fuzzy logic controller can be achieved

The first fuzzy logic chip was designed by Togai and Watanabe [22] in 1985 These fuzzy logic chips and computers [22-25] have been developed to speed up the fuzzy inference processing The inference mechanism embedded in the VLSI chip is the max-min logic operation A fuzzy logic accelerator (FLA) and fuzzy processor based on this chip are also available now (26,27)

In 1986, Yamakawa and Miki [23] developed basic fuzzy logic functions using the standard CMOS process in current-mode circuit system

In 1990 Lim and Takefuji [25] pointed out that incorporating reasoning systems in hardware is significant because expert system have to take a decision in real-time Reasoning system hardware for a fuzzy processor system requires developing two stages defining the fuzzy reasoning algorithm and designing special-purpose hardware

These fuzzy chips and computers will speed up the application of fuzzy logic controllers to intelligent robot systems

2.1.4 Fuzzy Logic in Industrial Applications

In 1992 Quail and Adnan [28] have provided an excellent review of the wealth of industrial product and consumer appliances that are bringing fuzzy logic application to the market place In their paper they presented the state-of-art in appliance technology usmg fuzzy set theory It has been suggested that in the house of the future, fuzzy logic will be commonly used in household appliances which will automatically adjust to room factors such as the number of people present, temperature and light levels or even the cleanliness of the floor and in some cases, the appliances will even operate themselves They commented that fuzzy logic has helped bring these dreams to the achievable present It appears that this theory has entered many aspects of Japanese life and even some areas in the U S such as automotive [29, 30, 31, 32, 33] air and spacecraft [40] and even the stock exchange [31, 32, 34] The concept of the fuzzy-controlled future home has already appeared in Japanese trade shows and households Numerous appliance applications use fuzzy logic to achieve design goals First goal is that the appliance be simple to operate The second is that the appliance have a short development time The third is that the appliance be cost effective compared to its standard logic counterpart and finally the design should be dynamic, with the ability to adjust to new inputs and different users

Dr Zadeh could not have foreseen the electronic revolution that his obscure fuzzy set theory has produced However, soon he predicts fuzzy logic will be part of every appliance "We'll see appliances rated not on horse power but on IQ" [35] In Japan, the revolution has been so strong that "fuzzy" has become a household word [36] The Japanese use the term positively to denote intelligence Almost all electronic products are based on fuzzy technology [37] "In Japan, electronics goods with fuzzy logic are already so popular that it seems to me that those that do not offer fuzzy applications within a few years will not be able to survive" [38]

The growing trend is to streamline housework and to use the available time more effectively Appliances with fuzzy logic controllers provide the consumer with optimum settings that more closely approximate human perceptions and reactions than standard control systems Products with fuzzy logic monitor user-dictated settings then automatically set the equipment to function at the user's generally preferred level for a given task [39] The technology is well suited to making adjustments in temperature, speed and other control conditions found in a wide variety of consumer products [38]

The following paragraphs discuss fuzzy logic as applied to various appliances

Washing Machine and Dryer

In 1991, in a journal of Electronics Industry, was described a basic neuro-fuzzy washing machine which uses sensors for water temperature and fabric type, then automatically selects one of 250 modes These washing modes optimise water temperature, water level, washing and cycle time and spin-drying time [38, 41, 42]

The Sharp Domestic Appliance Manufacturer took a different step to make a variation on the basic machine that shoots bubbles into the wash to completely dissolve detergent The efficiency of this machine is increased by 20% over non-fuzzy machines, as claimed in a Japanese consumer electronics report in 1991 [43]

Some models go a step further These models are equipped with two optical sensors that can sense the quality and quantity of dirt in the wash [44, 45] The pair of sensors determine the degree of soiling from the wash waters turbidity and also whether the stain was caused by oil or mud They also discriminate between liquid or powder detergents and meter the amount of detergent required [46] The fuzzy controller analyses the accumulated data and then selects the most efficient cleaning method from approximately 600 possible choices [45, 47]

The companion dryer uses three heat sensors that monitor load size, fabric type and hot-air flow The fuzzy controller determines the optimum drying time, shutting itself off when the contents are dry [46, 48], thus saving on time and energy costs

Vacuum Cleaner

Mitsusada has described in the Japanese Economic Journal in 1996 [42] that the basic fuzzy logic vacuum cleaner uses a single sensor to judge the amount of dust and the floor type By monitoring the change in dust, the controller decides whether the floor is bare, where the dust comes up at once, or thick-pile carpeting, where the dust is gradually released Based on that data, the fuzzy controller correlates the best suction power and beater-bar speed for each specific job For example when a hard floor is detected the motor and beater-bar are slowed because not much suction is needed [49]

In addition to analysing the floor type and amount of dust, the neuro-fuzzy version also analyses the type of dirt This information is used to adjust both the suction power and brush rotation speed for a 45% increase in cleaning speed [48] The efficiency and power savings in these cleaners is greatly increased over conventional vacuums Another variation of the basic fuzzy model is the Toshiba vacuum which advertises power steering along with all of its fuzzy features [35]

Microwave Oven

According to Remich and Norman [46] the basic fuzzy-logic microwave oven uses three sensors infrared, humidity and ambient temperature The sensors monitor the temperature of the food and oven cavity as well as the amount of steam emanating from the food [46] Based on this information, the fuzzy controller performs calculation on the type, size and weight of the food, whether it is frozen or thawed, whether the oven had been used immediately beforehand and the degree of "aloneness" The system results in the most efficient cooking time and usage of cooking condition such as roasting or hot-air-blower [46, 50] All of the microwaves advertise one touch operation and use fuzzy logic to simulate a cook's best judgement [50]

Refrigerator

Fuzzy logic has been used in Kenmore's premier model to determine the most efficient time to defrost as described by Rogers and Hoshai in 1992 [35] But Sharp has taken this application of fuzzy logic much further This model uses a neuro-fuzzy logic control system that learns the consumer's usage patterns for optimum operation [51]

The Sharp refrigerator memorises the time and frequency of freezer door and drawer openings When the usage pattern is learned for each compartment, the fuzzy control system automatically begins a cooling cycle before heavy traffic periods This feature minimises temperature fluctuations in the compartments [51]

Based on the memorised information, the unit also chooses the most appropriate time of day to defrost [52] An additional feature tells the unit not to make ice at night which may disturb light sleepers The consumer pushes a button on the unit before going to sleep in the night and the system memorises this time and repeat this pattern every night [51]

Air Conditioner

The application of fuzzy logic to air conditioners was first conducted by Mitsubishi heavy industries in October 1989 The system uses 50 fuzzy rules, max-product inferencing and centroid defuzzification methods A thermistor was used to detect room temperature and to control the inverter, compressor value, fan motor and heat exchanger The results from both the simulation and production showed (compared to the standard system) a 20% reduction in heating and cooling times, a two-fold increase in temperature stability and an overall power saving of 76% for the simulation and 24% in production

Newer models have sensors that evaluates the shape/size of a room and the inside/outside temperature and humidity levels By using an infrared sensor, the unit also determines the number of people present and cools the room accordingly [35] These inputs are used by the fuzzy controller to balance the room temperature with the power needs of the house resulting in the greatest possible efficiency [36, 42]

Dishwasher

In 1990 Reid [36] has applied fuzzy logic to dishwasher control This fuzzy appliance detects the number of dishes loaded and the amount and type of food attached on the plates The fuzzy controller efficiently varies the soap, water and cycle time based on these data

Rice Cooker

In 1990 the application of fuzzy logic to a rice cooker was conducted by Johnson, [53] This rice cooker uses three sensors to monitor the steam temperature and the volume of rice A similar work on a rice cooker was also reported by Remich, et al in 1991 [46] and 1992 [48] Once a minute, the sensors are checked and the remaining cooking time is calculated The unit has four pre-programmed settings for different types of rice such as white, porridge, glutinous (sticky) and mixed variety

Toaster

The application of fuzzy logic to a toaster was also conducted by Reid [36] in 1990. This particular toaster with fuzzy logic inside was termed "smart". The toaster adjusts the heat and toasting time depending on the type of bread it senses in the toaster. The user's preferences are also learned and memorised.

2.1.5 Application Of Fuzzy Logic In Medical Diagnosis

Weinberg and Breggear [1991] [54] have applied a fuzzy set data base search methodology for the modelling of adverse animal reaction in drug research. The model utilises a mathematical fuzzy set algorithm to identify links between the molecular structure of a new compound and regressively related molecular structures of compounds with known adverse animal reactions. Initial predictive trials have shown a reliability in excess of 95% and it has been concluded that fuzzy set algorithms and the regression approach represent a highly promising and immediately applicable alternative to live animal research in pre-investigatory new drug (pre-IND) pharmaceutical development settings.

Meier et al, 1992 [55] have used a fuzzy logic controller to control mean arterial pressure (MAP) which was taken as a measure of the depth of anaesthesia. The main reason for automating the control of depth of anaesthesia is to release the anaesthetist so that he or she can devote attention to other tasks as well - such as controlling fluid balance, ventilation and drug application - that cannot yet be adequately automated and thus to increase the patient's safety. The model used a rule-based controller and the design process was interactive with the membership functions as well as the linguistic rules determined by trial and error.

Tsutsui, and Arita, [56] have constructed a closed-loop blood pressure control system using fuzzy logic during enflurane anaesthesia. Four fuzzy rules were constructed, based on published anaesthetic values to determine the relationship between the changes of input variables and output values. Anaesthetic control started with the first map and was maintained with the succeeding maps. It has been claimed that during anaesthesia, the systolic blood pressure (SBP) remained within plus or minus 20% of the preanesthetic SBPs in 82% of the fuzzy control cases and within 83% during manual control. The difference was not significant. The anaesthetist's management of the administration of the inhaled anaesthetic enflurane was imitated by fuzzy logic control of the blood pressure.

2.2 Literature Survey Of Machinability.

2.2.1 Introduction.

A good amount of work regarding the machining of high to mild strength materials has been reported so far. The following review is based on the turning of mild and high strength material.

The following review is in relation to the surface finish, tool life, and cutting speed obtained during turning of mild and high strength materials.

2.2.2 Machinability Assessment

Shaw and Nakyama [57] have discussed in great details the important aspects involved in machining various materials. In summary, they suggest that for machining high strength materials, the tool should be refractory to avoid plastic flow, have high wear resistant to avoid wear and have good brittle fracture resistance to avoid chipping.

Taraman [58] has developed some mathematical models for cutting force, surface finish and tool life in terms of cutting speed, feed and depth of cut. The tests were carried out under dry conditions and he developed the following equations based on the experimental results.

$$Fc = 560V^{-0.16} f^{0.775} d^{0.665}$$

$$T = 24949\, V^{-1.406} f^{-0.248} d^{0.177}$$

$$R = 4626\, V^{-0.363} f^{1.1371} d^{0.1835}$$

Where

Fc is cutting force (N)	**V is cutting speed (m/min)**
T is tool life (Hours)	**f is feed rate (mm/rev)**
R is surface roughness	**d is depth of cut (mm)**

From these equations it has been concluded that a reduction in all the investigated outputs (cutting force, surface roughness and tool life) is achieved with increase in the cutting speed But if the feed increases, the surface roughness and cutting force increases while the tool life is reduced An increase in the depth of cut reduces tool life and causes an increase in surface roughness and cutting force It has also been noted that feed effect is dominant on surface roughness and the tool life is affected most by cutting speed, less affected by feed rate and least affected by depth of cut

Chang and Fuh [59] have studied the cutting performance in turning plain carbon steel using three kinds of tools i e TiN-coated, TiCN-coated and uncoated cemented carbide tools with chamfered main cutting edge (CMCE) They have also used pure aluminium to study the mechanism of secondary chip formation A special tool holder and its geometry was designed for carrying out this study In the overall performance, the coated CMCE tools were better than the uncoated CMCE In regard to the cutting force, the surface roughness of the work piece and the temperature of the tip surface, the levels of coated CMCE tools were all smaller than for the uncoated ones The cutting force for the TiCN-coated CMCE tools was smaller than that of the tin-coated ones From the surface roughness of the work piece, the tin-coated CMCE tools showed better results From the colour of the main chip and the hardness of the secondary chip, the temperature of the secondary chip was determined to be higher than that of the main chip

Research was conducted by Lin et al [60] to study the machinability of a silicon carbide reinforced aluminium metal matrix composite Continuous turning of round composite bars using tools with 25mm polycrystalline diamond (PCD) inserts was selected as the test method Various cutting speeds and feed rates were selected for the test while depth of cut were kept constant The performance of the tools was based on development of 0 25mm maximum flank wear, which were monitored by optical and scanning electron microscopy They have found out from their test results that the time required to reach the tool wear limit decreased with the increases of speed and feed However, the volume of material removed before reaching the wear limit actually increases with the higher feed rate

Wilson and El-Baradie [61] carried out a number of turning tests on Vitallium, a cobalt base alloy, to investigate cutting forces, tool wear and surface finish using carbide and cubic boron nitride (CBN) inserts having three different rake angles. The test result showed a very high cutting forces up to 1000 N at a feed rate of 0.08mm/rev and a depth of cut 0.25mm. Smallest cutting forces resulted from using the cutting tool with a positive rake angle. The wear of carbide tool with negative rake angle and low cutting speed (<20m/min) was a combination of adhesive, abrasive and diffusive wear. With CBN inserts, flank wear curves did not show the three distinctive zones (initial rapid wear, steady wear, and final abrupt wear). They noticed when the cutting speed was in excess of 30 m/min, the surface finish produced by the carbide tool was improved. The surface finish using CBN tools was extremely good.

Huet and Kramer [62] and Wright and Chow [63] have conducted some researches to find the relationship between the cutting speed and temperature of the cutting edge during machining of nickel alloys such as inconel 718 and nimonic 75. Their test result showed that at low speeds, the rate of increases of temperature of the cutting edge was very high and as the speed increased, this gradient was found to decrease.

Albrao et al [64] presented tool life data for various grades of conventional ceramic and PCBN cutting tool materials when turning hardened AISI H13 hot work die steel - (52 HRC) and hardened AISI E52100 bearing steel (62 HRC). They also evaluated in details some aspects of surface integrity following roughing and finishing operations. Their test include 3D mapping of surface texture and analysis of microstructure and microhardness variation. These test results indicated that when maching the hot work die steel and finishing the bearing steel low concentration PCBN and mixed alumina tooling provided the longest tool lives.

Dam et al [65] carried out a general survey of the processes that govern the ultrasonic maching of ceramics. The experiments were carried out by drilling holes in seven different ceramics and the aspects considered were production rate, tool wear, precision and surface quality. In their investigation they found that tough materials gave a low production rate, a high tool wear and a low surface roughness. For brittle materials the relationships were reversed - that was high production rate, low tool wear and high surface roughness. However they came to a conclusion that there were important quantitative differences in the machined surfaces. Generally tough materials gave material removed based on plasticity, and there seemed to be a greater tendency for dense and non-porous materials to produce surfaces with texture.

Komanduri and Schroeder [66] have produced machining conditions between the cutting speed and the chips formed from their maching test of high strength material (400 BHN). At lower speed (< 30 m/min), the chips were continuous and coiled while shear localization of the chip began at speed between 30 to 90 m/min and the segments were joined together in long coils. Isolated segments of chips were formed when the cutting speed was above 150m/min.

Sadat [67] conducted some experiments using natural and controlled contact length at various cutting speeds under dry and lubricated conditions to machine high strength material such as inconel 718 (38 RC) to examine the surface characteristics. He selected a constant feed rate (0.01 mm/rev) and four levels of cutting speed (6.6, 18, 36 and 60 m/min) for these tests. For a given cutting speed, both the tangential and feed forces were lower under controlled contact length of 0.15mm as compared to 0.39mm contact length. These tool forces decreased with an increase in cutting speed. The effect of lubrications on the tool forces was negligible at high speed cutting and the forces decreased with the increase of cutting speed.

Investigation was carried out by Dontamsetti and Fischer [68] to find out the factors affecting surface roughness in finish turning of grey cast iron (195 BHN). They used uncoated tungsten carbide inserts. Four levels of cutting speed and feed rate, two levels of nose radius and three levels of tool were used as independent variables. The cutting speed, feed and nose radius had significant affect on surface roughness. Interactions between tool wear and each of the other three variables were also highly significant.

Lim [69] has investigated the wear on the tool for an effective unmanned machine-turning system. He suggested that changes in the tool wear can be detected in the vibration signatures during the machine turning operation. It was found that at various cutting speeds, the vibration amplitudes consistently produce two peaks throughout the life of the tool and also there was a strong correlation between the tool flank wear and the acceleration amplitude. He suggested that this signal can be incorporated in a software program for an on-line monitoring system to indicate the onset of tool failure thus assessing the life of the cutting tool and also improving cutting performance.

Mital and Mehta [70] conducted an experiment to collect surface finish data for a wide variety of metals and alloys (aluminium alloys 390 (71.5 BHN), ductile cast iron (183 BHN), medium carbon leaded steel 10L45 (197 BHN), medium carbon alloy steel 4130 (195 BHN) and inconel 718 (340 BHN) for a wide range of machining conditions. They used a randomised complete block factorial design with four levels of feed rates (0.0508, 0.127, 0.2032 and 0.3048 mm/rev) and three nose radii (0.794, 1.190 and 1.587mm). Three levels of cutting speeds (243.8, 304.8 and 365.7 m/min) and (167.6, 213.4 and 259.1 m/min) were used for machining tests of medium carbon leaded steel 10L45 and medium carbon alloy steel 4130 respectively. In case of medium carbon leaded steel 10L45 the surface finish improved significantly with tool nose radius ($p > 0.01$), but deteriorated with feed (effect significant at less than 1% level). The effect of speed was mixed and the surface finish improved as the cutting speed increased to 304.8 m/min. In case of medium carbon alloy steel 4130 the results were similar to those obtained for medium carbon leaded steel 10L45. The results of their study indicated that the machining conditions for different metals significantly influenced their surface finish. The effect of feed was found to be more profound than either the effect of cutting tool nose radius or the effect of cutting speed. They suggested that it helps to employ a cutting tool with larger nose radius - because the surface finish improved with the tool nose radius. In their investigation the negative and positive correlation's between speed and surface finish for different metals indicated that the generalisation that higher speeds always lead to superior finish is invalid while surface finish may improve with speed for some materials, it may deteriorate for others. Similar conclusions were drawn by Karmaker 1970 [71] for medium carbon steel, using ceramic tools and Chandiramani and Cook 1964 [72] for leaded and resulphurized steels, using carbide tools.

Yaguchi [73] carried out a set of experiments to measure the cutting forces and to observe chip morphology in hot and cold drawn bars of AISI 12L14 steel. The cutting force of cold drawn bars was found to be significantly lower than that of hot rolled bars, whereas only slight difference were detected in chip thickness.

Ohtani and Yokogawa [74] have investigated the wear mechanism of the cubic boron nitride (CBN), ceramic and carbide tools and cutting forces encountered when turning tool steel having several levels of hardness ranging from $18R_c$ - $60R_c$. A constant depth of cut 0.2mm and feed rate of 0.1 mm/rev and three levels of cutting speeds (100, 150 and 200 m/min) were used under dry condition. They found that the life span of carbide tools decreased as the hardness of the workpiece increased, while the life span of CBN and ceramic tools showed the opposite results. They also found the tool failure for CBN and ceramic was abrasion wear by hard alloy carbide particles contained in the workpiece. The increasing rates of cutting force components against flank wear were slower for carbide tools than for the other tool. They concluded that the stress distributed on the worn flank face was lower in carbide tools.

Akhtar et al [75] tested the machinability of 14 casts of low carbon free machining steel by the study of the wear of M2 high speed steel tools and tests were carried out according to the International Standards Organisation testing procedures. The curves of the tool wear showed that the flank wear land width decreases with increase in cutting speed or flank wear rate. They proposed a short-time test based on tool wear which can be extrapolated either numerically or graphically to give the time of failure of the tool.

Enomoto et al [76] carried out a set of experiments to test the effect of work material hardness on the cutting tool life. They used cubic boron nitride (CBN) and carbide tools in the turning of chromium-molybdenum steels The CBN tool gave the shortest tool life when the hardness was low On the contrary the carbide tool exhibited shorter tool life with increase in work material hardness

Bandyopadhyay and Teo [77] developed surface roughness prediction models for high speed dry turning using coated carbide inserts They evaluated the effects of cutting speed, feed and depth of cut on the surface finish based on the factorial design of experiments Five levels of speed (200, 285, 400, 560 and 800 m/min), feed (0 0584, 0 0737, 0 094, 0 1168 and 0 1480 mm/rev) and depth of cut (0 344, 0 50, 0 71, 1 0 and 1 454 mm) were used in the experiments The workpiece material was SAE 1020, 250mm long and 155mm in diameter They came to a conclusion that the predicted roughness was significantly affected by the feed rate Cutting speed and depth of cut had a minor effect The experiments showed that surface finish improved with the increase of cutting speed

El-Baradie [78] developed a surface roughness prediction model using carbide inserts under dry conditions for turning grey cast iron (154 BHN) The model was based on cutting speed, feed rate, tool nose radius and a constant depth of cut His model showed that an increase in either the cutting speed or the tool nose radius decrease the surface roughness, while an increase m the feed increases the surface roughness

CHAPTER 3 FUZZY LOGIC THEORY

3.1 Introduction

Fuzzy logic theory was developed in 1965 by Lofti Zadeh [1], a professor of the University of California at Berkeley Traditional set theory models the world as true or false An element is a member of a certain group or not Zadeh extended this theory so that an element can be a member of a particular set with a certain degree of truth, ranging from 0 to 1 Zero represents false and 1 represents absolute truth The dual logic used in traditional set theory has been proven very effective and successful in solving many well defined problems, which are characterised by precise descriptions of the process being dealt with in quantitative form However there are many situations where the traditional set theory may prove inadequate, in that, problems exist which are complex and ill-structural in nature and do not lend themselves to such quantification These types of problems are usually left for human beings to deal with One is no longer dealing with clear-cut concepts like yes or no, but with vague concepts such as more or less true From such realisations, fuzzy set theory emerged Therefore fuzzy set theory can be viewed as one approach for dealing with these problems

Zadeh introduced the theory of fuzzy sets as an extension to traditional set theory, along with the fuzzy logic to manipulate the fuzzy sets The beauty of fuzzy logic is that it allows an element to have a degree of membership in the set other than 0 or 1

As an example of fuzzy logic, consider classifying people using their height In traditional set theory, classes are built with height boundaries such as the 'short' set runs from 4 feet to 5 feet as shown in Fig 3 1, but the problem is that for someone whose height is just over 4 feet, 4 001 say, is classified in a totally different way to someone just under 4 feet, 3 999 say, although they are almost identical The classification is discontinuous

In this situation fuzzy logic theory helps to solve the problem by allowing classes with 'soft' boundaries For example lets take the case of Lucy who is 5 feet 6 inches in height Lucy could be said to belong to the medium tall class and tall class A level of membership will be associated with Lucy from both classes She will belong to the class medium tall with a degree of membership of 0 8 and also she belongs to the class tall with a degree of membership of 0 3 as shown in Fig 3 2 That means she is considered to be more medium tall than tall while accepting her to be considered tall to a certain extent

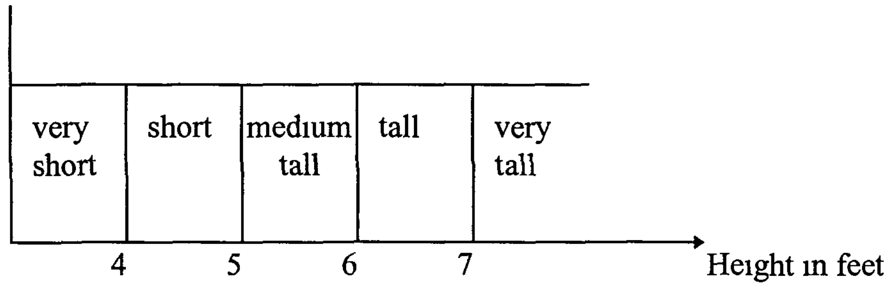


Fig. 3.1 Traditional point of view

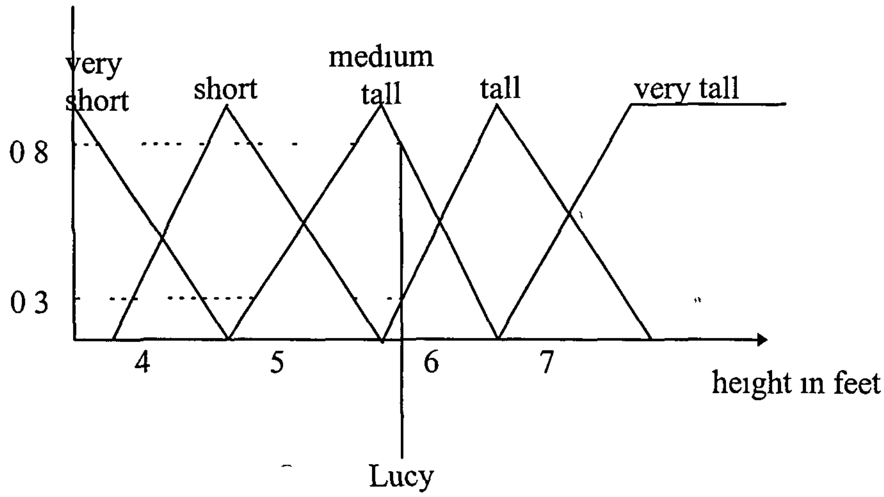


Fig. 3.2 Fuzzy point of view

A membership function defines the grade of membership in a fuzzy set for all the possible members and is usually expressed as a mathematical function or a set of discrete digital numbers Fuzzy logic theory permits human observations, expertise knowledge and expressions to be more closely modelled Since its introduction, fuzzy logic theory has attracted the attention of many researches in mathematical and engineering fields Fuzzy set theory has been successfully established as an alternative approach to reasoning under uncertainty. Fuzzy logic has been applied in many areas, including process control, expert systems, pattern recognition and linguistics many areas, including process control, expert systems, pattern recognition and linguistics

3.2 Crisps Sets and Fuzzy Sets

An ordinary 'crisp' set is defined by identifying those items which it contains for a given universe of discourse Each item or element in the universe either belongs to the set or not The function X_A of A gives each element of the universe a membership value of either 1 or 0 The value 1 is assigned to each item in the universe when the item has the property value 'true' or 0 when the item has the property value "false" Usually it is expressed by the notation $A = \{ x \cdot P(x) \}$ where P is the property and P(x) = 'true' if and only if $X_A(x) = 1$ The introduction of the fuzzy sets are based on the idea of extending the range of the function so that it covers the real interval [0,1]

The membership value assigned to an item in the universe is no longer confined to just two possibilities, but it can be 1, 0 and any value in between, such as 5, 2, 8 etc The membership property associated with a fuzzy set thus gives a wider band of truth values than just 'true' or 'false' Fuzzy logic thus poses as multivalued logic which is different from traditional two valued logic Real life is full of complex situations where things do not fit well into a 'crisp' framework for example a medical treatment may depend on the patient's age whether the patient is 'young', 'middle-aged' or 'old' The classification of the age can be done as follows

Youth	age < 35 years
Middle age	35 ≤ age < 55 years
Old age	age ≥ 55 years

The application of the 'crisp' approach to define the term middle-age does violence to the underlying concept because it is inherently discontinuous and classifying ages of 54 and 55 as being quite different Therefore it is not a good fit for a continuous process such as ageing age' than the cnsp set as shown ın Fıg 3 4 If a cnsp approach were used then a guıdelıne ıs needed for explaınıng how to deal wıth the cases near the group boundanes

Fuzzy sets correspondıng to 'youth and 'old age' can also be defined ın the same way as shown ın Fıg 3 5 The overlappıng of sets sımply reflect the fact that an age 60 can be a member of both groups such as 'mıddle-age' and 'old age' There are no sudden changes ın age group As age ıncreases, membershıp ın 'youth' gradually decreases to 0, ınstead of suddenly changıng from 1 to 0 Soft boundanes of the age-group ranges over a much more lımıted set of values Each age group 'youth', 'mıddle-age' and 'old age' ıs regarded as a fuzzy set and has a correspondıng lınguıstıc value Two dıfferent vanables are related to age

1 Age-ın-years ------- A numencal vanable
with ınteger numencal values

11 Age-group --------- A lınguıstıc vanable
takıng the lınguıstıc values
'youth', 'mıddle-age' and 'old age'

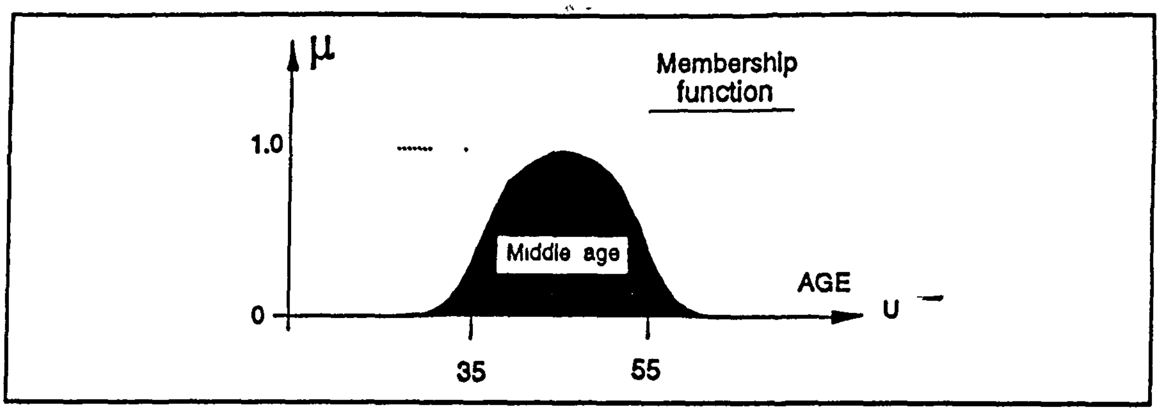


Fig 3.3 Fuzzy Set - 'Middle Age'

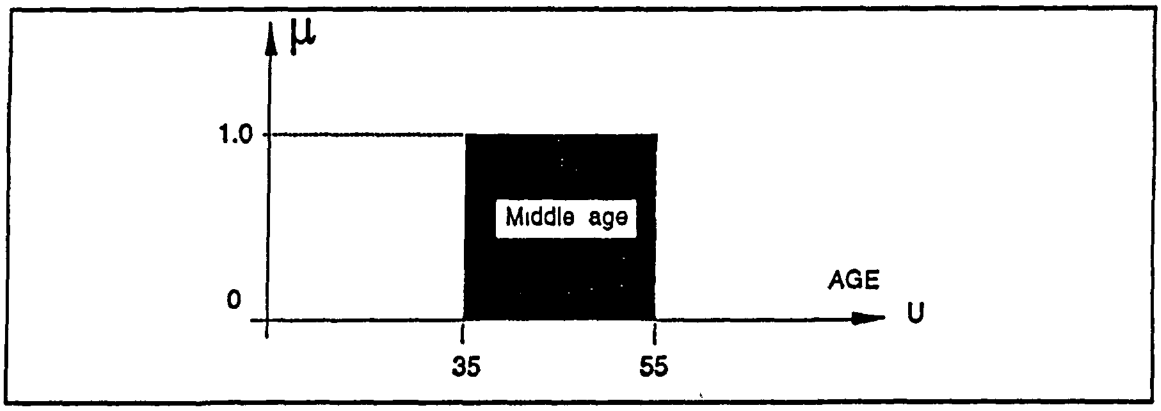


Fig 3.4 Crisp Set - 'Middle Age'

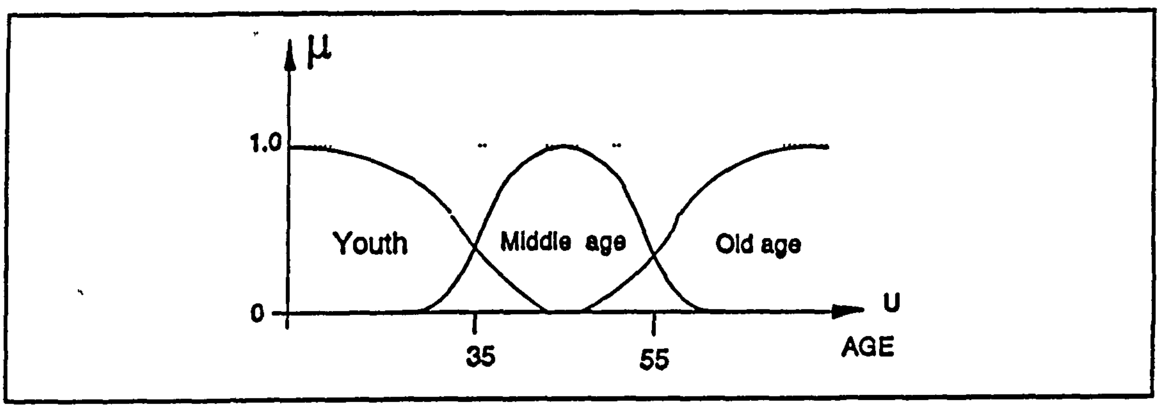


Fig 3.5 Age Groups as Fuzzy Sets

3.3 Membership functions

Membership for fuzzy sets can be defined two ways: numerical and functional. A numerical definition expresses the degree of membership function of a fuzzy set as a vector of numbers whose dimension depends on the level of discretisation. A functional definition defines the membership function of a fuzzy set in an analytic expression which allows the membership grade for each element in the defined universe of discourse to be calculated. There are certain standard shapes of membership functions commonly used for fuzzy sets which are based on the universe U of real numbers. Depending on the application, a membership function can be defined in different forms such as a) S-Function, b) π-Function, c) triangular form, d) trapezoid form and e) exponential form.

The S-Function is defined as follows:

$$S(u; a, b, c) = \begin{cases} 0 & \text{for } u \leq a \\ 2\,[(u-a)/(c-a)]^2 & \text{for } a \geq u \leq b \\ 1-2\,[(u-c)/(c-a)]^2 & \text{for } b \leq u \leq c \\ 1 & \text{for } u > c \end{cases} \qquad (3\text{-}1)$$

Function in this type have an 'S' shape whose precise appearance is determined by the value of the parameters a, b, c as illustrated in Fig 3.6.

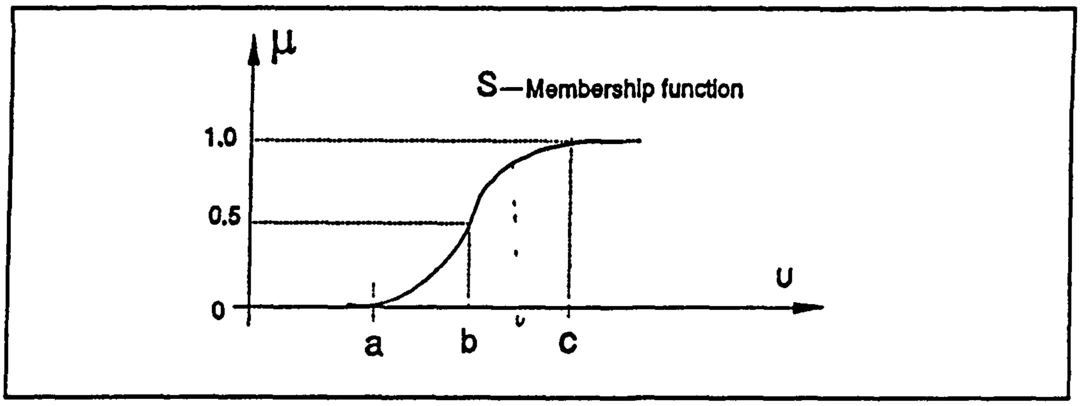


Fig. 3.6 The S-function

The S-Function is flat at a value of 0 for $u \leq a$ and at 1 for $u \geq c$. In between a and e that S - function is a quadratic function of u. The crossover point of 0.5 occurs at $b = (a + c)/2$.

The π - function is defined as follows.

$$\pi(u;b,c) = \begin{cases} S(u, c-b, c-b/2, c) & \text{for } u \le c \\ 1-S(u; c, c+b/2, c+b) & \text{for } u \ge c \end{cases} \quad (3\text{-}2)$$

Functions in this family are roughly bell-shaped, with the sides of the bell being generated from S-Functions. Functions of this type can be useful alternative to triangular - functions, as they give a membership value which approaches 0 in a more gradual manner as shown in Fig 3.7.

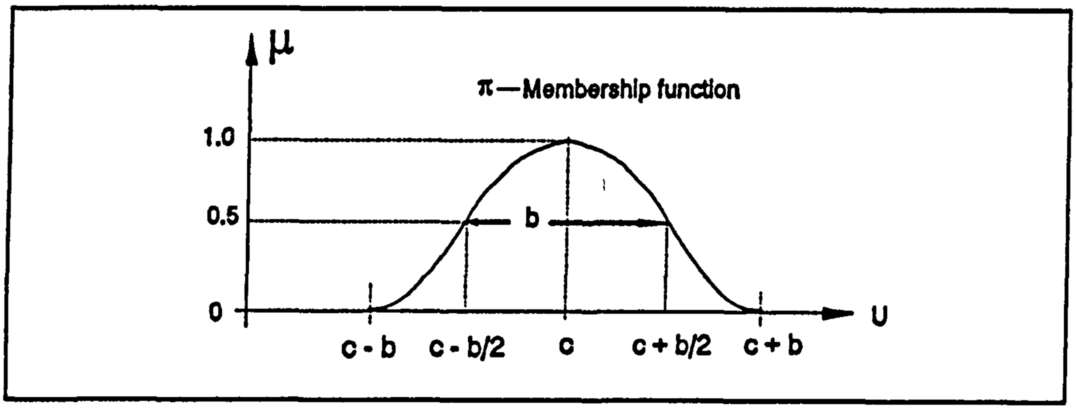


Fig. 3.7 The π - function

The b parameter is now the bandwidth at the crossover point. The π-function goes to 0 at the points $u = c \pm b$, while the crossover points are at $u = c \pm b/2$.

The Triangular function is defined as follows:

$$T(u; a, b, c) = \begin{cases} 0 & \text{for } u \le a \\ (u-a)/(b-a) & \text{for } a \le u \le b \\ (c-u)/(c-b) & \text{for } b \le u \le c \\ 0 & \text{for } u > c \end{cases} \quad (3\text{-}3)$$

Functions in this family have a triangular shape whose precise appearance is determined by the choice of parameters a, b, c as shown in Fig 3.8.

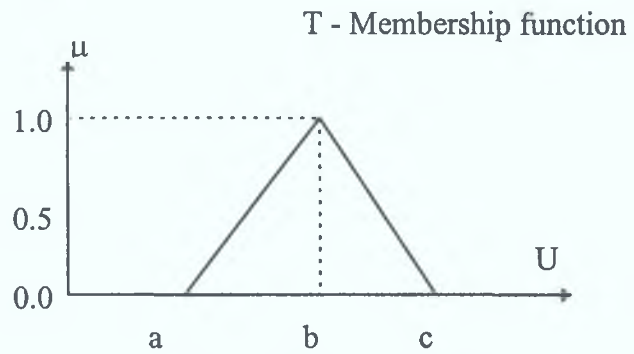


Fig. 3.8 The T- function

This function is commonly used in modelling properties that have non-zero membership for only a narrow range of values, with membership going to 0 for both large and small u.

3.4 Fuzzy Rule

The knowledge extracted from the operator may be organised in a logical control rules format which describes the behaviour of the skilled operator. A fuzzy algorithm can then be based upon observation and discussion with the operator. The rule base is generally constructed in the form of fuzzy conditional statements:

IF (a set of conditions are satisfied)
THEN (a set of consequences can be inferred)

For example in a metal welding operation the following four rules can be employed for the fuzzy controller as shown in Table 3.1.

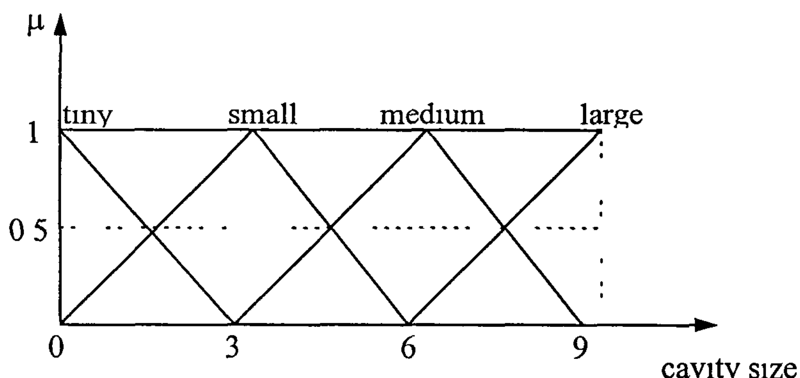
Table 3.1 Fuzzy Rules for Welding Operation

Rule 11: IF Cavity size is tiny THEN speed is Fast
Rule 12: IF Cavity size is small THEN speed is Regular
Rule 13: IF Cavity size is medium THEN speed is Slow
Rule 14: IF Cavity size is large THEN speed is Minimum

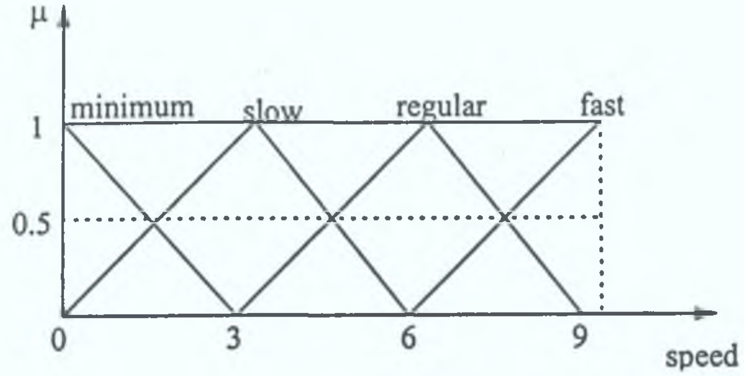
These rules are in the form of an expert system using fuzzy expressions such as Large, Fast, etc., which allows the machine to imitate the skills of the welding operator The ınput to the system ıs the cavıty sıze and the output ıs the movement (speed) of the hand

3.5 Fuzzy Partition of Input/Output Universe

The fuzzy sets defined for ınput varıables ın the antecedent of a fuzzy control rule form a fuzzy ınput space wıth respect to the ınput unıverse of dıscourse whıle those ın the consequent of a fuzzy control rule form a fuzzy output space A fuzzy partıtıon determınes how many fuzzy sets should be defined for each varıable along ıts unıverse of dıscourse The number of fuzzy sets m a fuzzy ınput space ımposes restrıctıons on the maxımum number of fuzzy control rules that can be constructed But ıt should be taken ınto consıderatıon that the fuzzy partıtıon of the fuzzy ınput/output space ıs not determınıstıc and has no unıque solutıon A trıal procedure ıs usually needed to find a optımal partıtıon The ınput unıverse should be partıtıoned accordıng to the mınımum and maxımum values allowed to control the system For example, the ınput unıverse of cavıty sıze mıght be splıt ınto 9 unıts, because e g the maxımum value allowed to control the process ıs approxımately three tımes the dıameter of the electrode whıch ıs usually 3 mm The output unıverse (speed) ıs splıt ınto 15 unıts accordıng to the range of speed requıred, whıch ıs between 20 and 35 cm/mm Any value above thıs range assumed to be ınfinıty and a zero value ıs assumed to be the mınımum Example partıtıonıng of ınput cavıty sıze and output speed ıs shown below ın Fıg 3 9



a) Cavity Size Membership



b) Speed Membership

Fig 3.9 Membership Functions

3.6 Fuzzy Set Operation.

The use of fuzzy set operation provides a basis for the systematic manipulation of vague and imprecise concepts. The fuzzy set operations are performed through manipulating the membership functions involved. Some basic fuzzy set operations are summarised below.

Let A and B be two fuzzy sets based on the same universe with membership function μ_A and μ_B respectively. Then the following fuzzy set operations can be defined.

EQUALITY: Two fuzzy sets A and B are equal if they are defined on the same universe and the membership function is the same for both, that is

$$\mu_A(u) = \mu_B(u) \quad \text{for all } u \in U \tag{3-4}$$

Union : The union of two fuzzy sets A and B with membership functions $\mu_A(u)$ and $\mu_B(u)$ is the fuzzy set whose membership function $\mu_{(A \cup B)}(u)$ is given by

$$\mu_{A \cup B}(u) = \text{MAX}\{\mu_A(u), \mu_B(u)\} \text{ for all } u \in U \tag{3-5}$$

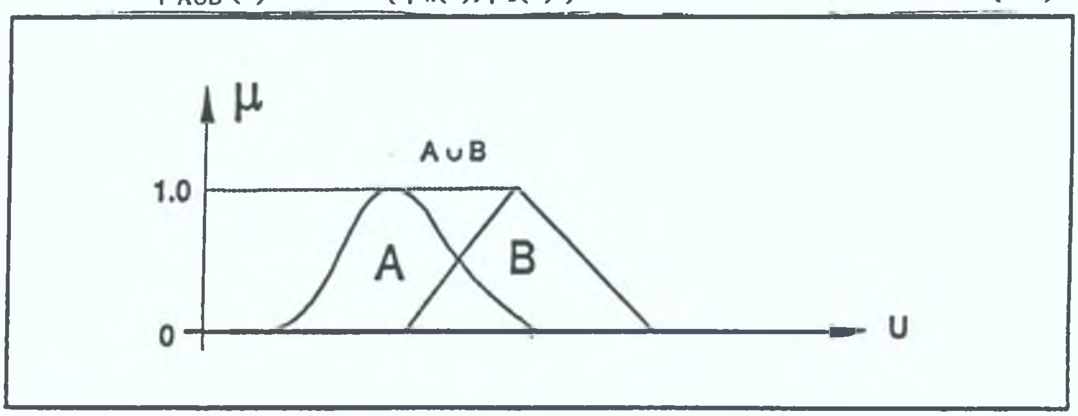


Fig 3.10 Union Operation

Intersection

The Intersection of two fuzzy sets A and B is the fuzzy set whose membership function is given by

$$\mu_{A \cap B}(u) = \min \{ \mu_A(u), \mu_B(u) \} \text{ for all } u \varepsilon U \qquad (3\text{-}6)$$

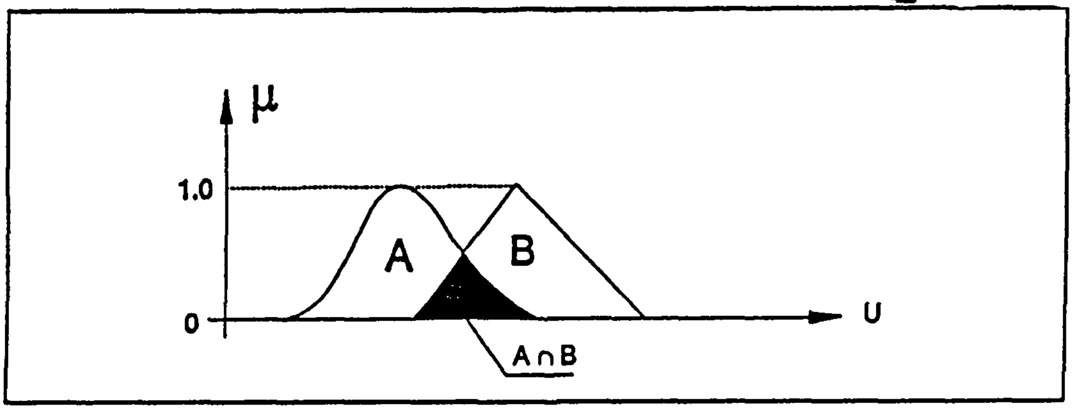


Fig 3.11 Intersection Operation

Complement

The complement of a fuzzy set A with membership function $\mu_A(u)$ is defined as the fuzzy set on the same universe with membership function:

$$\mu_{A'}(u) = 1 - \mu_A(u) \text{ for all } u \varepsilon U \qquad (3\text{-}7)$$

Note that the intersection of a fuzzy set and its complement need not be empty, unlike the crisp case. The closer the sets are to being crisp, the closer this intersection will be to being empty.

The Union of a fuzzy set and its complement need not be the universe, unlike the crisp case. The closer they are to being crisp, the closer this union will be to being the universe.

The only constraint on the intersection of a set and its complement is that:

$$\mu_{A \cap A'}(u) = \min \{\mu_A(u), \mu_{A'}(u) \} \leq 0.5 \qquad (3\text{-}8)$$

Likewise the only constraint on union is that

$$\mu_{A \cup A'}(u) = \max \{\mu_A(u), \mu_{A'}(u)\} \geq 0.5 \quad (3\text{-}9)$$

Depending on the membership function, various results can be achieved for fuzzy sets which have no corresponding feature for crisp sets.

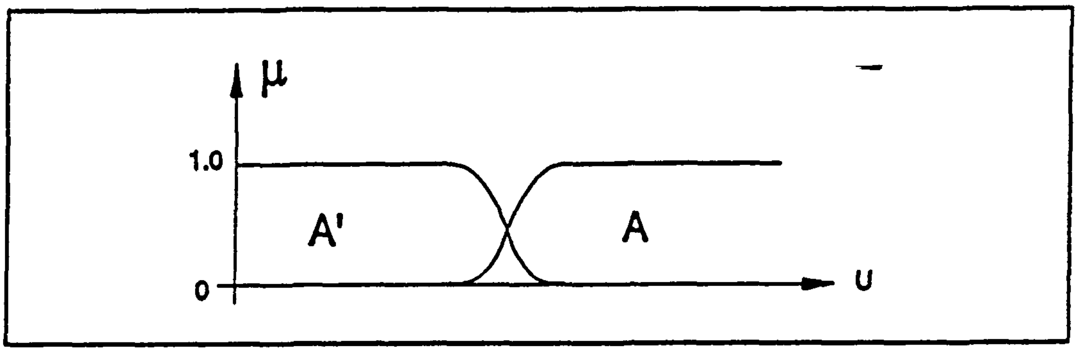


Fig 3.12 Fuzzy Complement

Normalisation

This process simply involves re-scaling the membership function so that its maximum value is 1, that is

$$\mu_{NORM(A)}(u) = \mu_A(u) / MAX(\mu_A(u)) \quad u \in U \quad (3\text{-}10)$$

Concentration

A fuzzy set A can be 'concentrated' by modifying its membership function $\mu_A(u)$ so as to accentuate the membership of the higher membership elements. This is done by squaring the normalised membership function, that is

$$\mu_{CON(A)}(u) = (\mu_A(u))^2 \quad \text{for all } u \in U \quad (3\text{-}11)$$

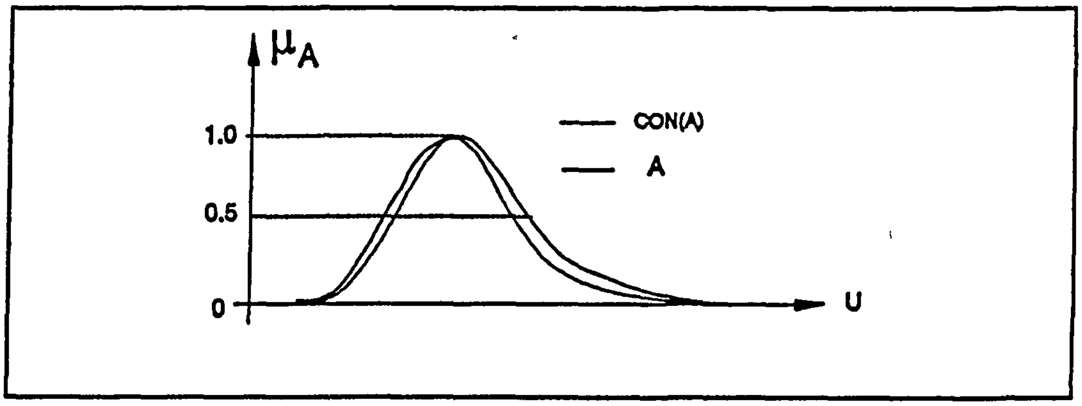


Fig 3.13 Concentration of a Fuzzy Set

Dilation

A fuzzy set A can be 'dilated' by modifying its membership function $\mu_A(u)$ to increase the importance of lower membership elements. This is done by taking the square root of the normalised membership function, that is

$$\mu_{DIL(A)}(u) = (\mu_A(u))^{0.5} \quad \text{for all } u \in U \tag{3-12}$$

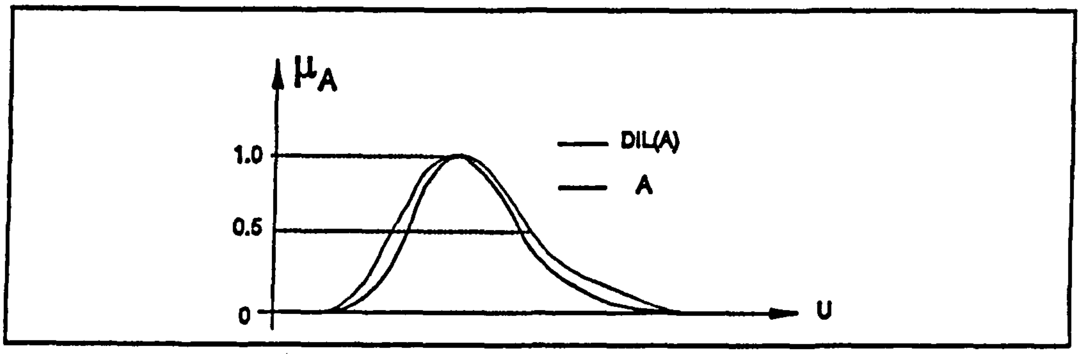


Fig 3.14 Dilation of a Fuzzy Set

Intensification

This operation moves the normalised fuzzy set closer to being crisp, by enhancing the membership value of those elements whose membership was above 0.5 and diminishing that of those elements with membership below 0.5. This corresponds to a contrast enhancement type of operation, as denoted by

$$\mu_{INT(A)}(u) = \begin{cases} 2(\mu_A(u))^2 & \text{for } 0 \leq \mu_A(u) \leq 0.5 \\ 1-2\,(1-\mu_A(u))^2 & \text{for } 0.5 \leq \mu_A(u) \leq 1 \end{cases} \tag{3-13}$$

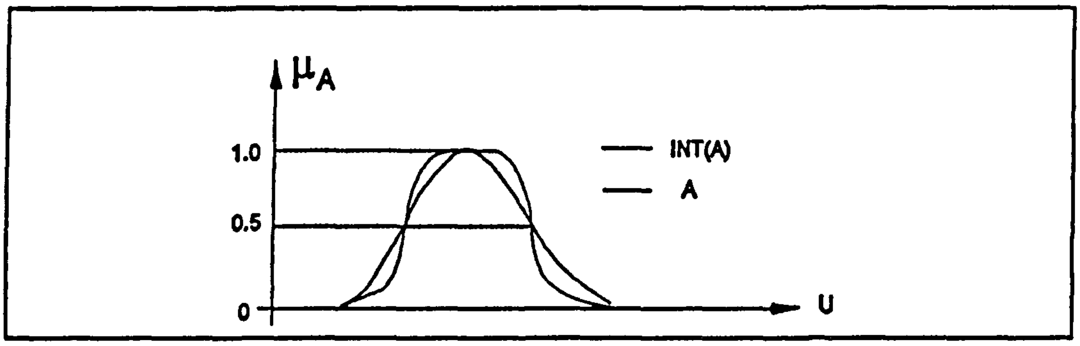


Fig 3.15 Intensification of a fuzzy set

Algebric Product

The algebric produce of two fuzzy sets A and B with membership function $\mu_A(u)$ and $\mu_B(u)$ is the fuzzy set whose membership function $\mu_{A \bullet B}(U)$ is given

$$\mu_{A \bullet B}(u) = \{\mu_A(u) \bullet \mu_B(u)\} \quad \text{for all } u \varepsilon U \qquad (3\text{-}14)$$

Bounded Sum

The bounded sum of two fuzzy sets A and B with membership functions $\mu_A(u)$ and $\mu_B(u)$ is the fuzzy set whose membership function $\mu_{A \oplus B}(U)$ is given

$$\mu_{A \oplus B}(u) = \min \{ 1, \mu_A(u) + \mu_B(u) \} \quad \text{for all } u \varepsilon U \qquad (3\text{-}15)$$

Where '+' is the arithmetic sum operator

Bounded Product

The bounded product of two fuzzy sets A and B with membership function $\mu_A(u)$ and $\mu_B(u)$ is the fuzzy set whose membership function $\mu_{AoB}(u)$ is given

$$\mu_{AoB}(u) = \max \{ 0, \mu_A(u) + \mu_B(u) - 1 \} \quad \text{for all } u \varepsilon U \qquad (3\text{-}16)$$

where '+' is the arithmetic sum operator

Drastic Product

The drastic product of two fuzzy sets A and B with membership functions $\mu_A(u)$ and $\mu_B(u)$ is the fuzzy set whose membership function $\mu_{A \otimes B}(U)$ is given

$$\mu_{A \otimes B}(U) = \begin{cases} \mu_A(u) & \text{for } \mu_B(u) = 1 \\ \mu_B(u) & \text{for } \mu_A(u) = 1 \\ 0 & \text{for } \mu_A(u), \mu_B(u) < 1 \end{cases} \qquad (3\text{-}17)$$

Cartesian Product

If A_1, A_2, A_3 ... A_n are fuzzy sets in U_1, U_2, U_3 ... U_n respectively, the Cartesian product of A_1, A_2, A_3 ... A_n is a fuzzy set F in the product space $U_1 \times U_2 \times U_3 \times$ ... U_n with the membership function

$$\mu_F(u_1 \ldots u_n) = \min\{\mu_{A1}(u_1) \ldots \mu_{An}(u_n)\} \text{ (min)} \quad (3\text{-}18)$$

Or

$$\mu_F(u_1 \ldots u_n) = \mu_{A1}(u_1) \ldots \mu_{An}(u_n) \text{ Product} \quad (3\text{-}19)$$

where $F = A_1 \times A_2 \times A_3 \times \ldots A_n$

Sup-Star Composition

IF A and B are fuzzy relation in U x V and V x W respectively, the composition of A and B is a fuzzy relation known as AoB, where AoB is denoted by

$$AoB = \{[(u,w), \sup(\mu_P(u,v) * \mu_B(v,w))], u\varepsilon U, v\varepsilon V, w\varepsilon W \quad (3\text{-}20)$$

Where * is the sup-star compositional operator and could be any compositional operator in the class of triangular norms, namely, minimum, algebric product bounded product, or drastic product

Example - The Max -Min based compositional operator plays an important role in establishing the fuzzy relation equation for a fuzzy knowledge base In fact, the composition operation is the net effect of applying one relation after another In most applications, the composition can be defined by max-min functions which deal with matrix product operations Let A and B be defined as follows

$$A = \begin{bmatrix} 0\,1 & 0\,4 \\ 0\,7 & 0\,9 \end{bmatrix} \qquad B = \begin{bmatrix} 0\,2 & 0\,6 & 0\,8 \\ 0\,7 & 0\,4 & 0\,5 \end{bmatrix}$$

Then the relation, R can be obtained using max-min compositional operations

$$R = AoB = \begin{bmatrix} 0\,1 & 0\,4 \\ 0\,7 & 0\,9 \end{bmatrix} o \begin{bmatrix} 0\,2 & 0\,6 & 0\,8 \\ 0\,7 & 0\,3 & 0\,5 \end{bmatrix}$$

$$= \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \end{bmatrix}$$

where

$$R_{11} = \text{Max}\{\min(0.1, 0.2), \min(0.4, 0.7)\}$$
$$= \text{Max}\{0.1, 0.4\}$$
$$= 0.4$$

$$R_{12} = \text{Max}\{\min(0.1, 0.6), \min(0.4, 0.3)\}$$
$$= \text{Max}\{0.1, 0.3\}$$
$$= 0.3$$

$$R_{13} = \text{Max}\{\min(0.1, 0.8), \min(0.4, 0.5)\}$$
$$= \text{Max}\{0.1, 0.4\}$$
$$= 0.4$$

$$R_{21} = \text{Max}\{\min(0.7, 0.2), \min(0.9, 0.7)\}$$
$$= \text{Max}\{0.2, 0.7\}$$
$$= 0.7$$

$$R_{22} = \text{Max}\{\min(0.7, 0.6), \min(0.9, 0.3)\}$$
$$= \text{Max}\{0.6, 0.3\}$$
$$= 0.6$$

$$R_{23} = \text{Max}\{\min(0.71, 0.82), \min(0.94, 0.57)\}$$
$$= \text{Max}\{0.7, 0.5\}$$
$$= 0.7$$

3.7 Fuzzy Relation.

The fuzzy relation is the relationship between the object in the condition section (known as 'input') and the object in the consequence section (known as 'output'). For example, the object in the condition section (or input) in rule base 1 (see table

3.1) is referred to "cavity size" while the object in the consequence section (or output) in rule base 1 is referred to "speed".

Let the object in the condition section of the jth rule base is denoted by $INPUT^j$ and the object in the consequence section of the jth rule be denoted by $OUTPUT^j$. Thus from Table 3.1 the $INPUT^j$ and $OUTPUT^j$ can be outlined as follows:

Table 3.2: INPUT and OUTPUT Terms

RULE BASE	$INPUT^j$	$OUTPUT^j$
1	Cavity Size	Speed

For the ith rule in jth rule base Rji, the fuzzy relation between the input and output can be denoted by

$$Rji = [INPUT^j]_i * [OUTPUT^j]_i \qquad (3\text{-}21)$$

where * denotes the cartesian product for fuzzy relations.

The membership function μRji, for the fuzzy relationship is given by:

$$\mu_{Rji} = MIN \{ \mu[INPUT^j]_i, \ \mu[OUTPUT^j]_i \} \qquad 3\text{-}22)$$

where

$\mu[INPUT^j]_i$ ----------- the membership in the descrete universe corresponding to the ith fuzzy input term in the condition section of the jth rule base.

$\mu[OUTPUT^j]_i$ -------- the membership in the descrete universe corresponding to the ith fuzzy output term in the consequence section of the jth rule base.

By combining all the rules in the jth rule base using the fuzzy operator "OR", the membership function for the relationship between the INPUT and OUTPUT of the jth rule base is given by

$$\mu_{Rj} = MAX \{ \mu Rj1, \mu Rj2, \mu Rj3 \text{ --------- } \mu Rjn\} \qquad (3\text{-}23)$$

Thus, the fuzzy relations between the INPUT and OUTPUT for all the rule bases can be established by using e.g. (3-5) and e.g (3-6).

The defuzzified output which gives the average speed value can be obtained from the following formula:

$$\text{Average value} = \sum \text{speed value} \times \mu(s) / \sum \mu(s) \qquad (3\text{-}24)$$

3.8 Fuzzy Set Shapes.

Different applications of the fuzzy control technique use specific shapes of the fuzzy sets which are dependent on the system behaviour identified by the knowledge engineer. So far there is no standard method of choosing the proper shape of the fuzzy set of the control variables. The scale suggested for the fuzzy variables of the control systems are termed "fuzzyimetric arcs". Since the main interest in this project is the application of the fuzzy control to manufacturing processes, the use of fuzzimetric arcs and the application of fuzzy control theory has been selected to demonstrate the more efficient metal cutting speed for different type of metal hardness.

The first step in establishing the fuzzy control system is the selection of the proper shape of fuzzy sets of the control variables based upon observation of the system behaviour. The fuzzy set shape is an influencing factor on the performance of the controller and may be altered to obtain the most suitable form of the fuzzy variables.

Since a fuzzy control algorithm is one means of imitating humans performance, the shape of the fuzzy sets of the control variables should be logical and acceptable to individuals. For example, as shown in Fig 3.16 for three fuzzy variables specified as very soft, soft and medium soft in a universe of discourse U, the output universe of discourse in metal cutting process would be all the possible values of the cutting speed

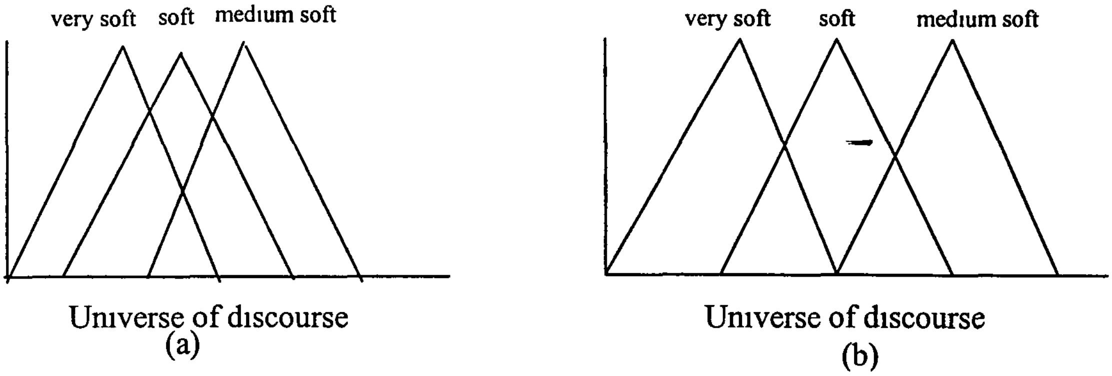


Fig 3.16 Difference between unacceptable (a) and acceptable (b) fuzzy set shape.

An overlap between medium soft and soft or an overlap between soft and very soft is logical and acceptable However an overlap between medium soft and very soft is not acceptable to individuals, especially when dealing with numeric application of the type considered in manufacturing process

The fuzzy system variables include input variables and output variables The input variables, known as process state variables, are measured from the controlled process, while the output variables, known as process control variables, are inferred from FLC (fuzzy logic control) The proper choice of input variables and output variables is essential to the successful design of a fuzzy control system The definition of the fuzzy set for each system variable has a substantial effect on the performance of an FLC

Depending on the complexity of the fuzzy system the number of input and output variables varies For a system with n input variables and m output variables, it is often called as n-input-m-output system In the case that n=1 and m=1, the fuzzy system is said single-input-single-output (SISO) In the case that $n \geq 2$ and $m = 1$, the fuzzy system is said multi-input-single-output (MISO) In the case that $n \geq 2$ and $m \geq 2$, the fuzzy system is said multi-input-multi-output (MIMO)

The fuzzy sets for each variable are defined in linguistic terms such as VS (Very Soft), SO (Soft), MS (Medium Soft), ME (Medium), MH (Medium Hard), HA

(Hard) and VH (Very Hard) etc The number of the fuzzy sets defined for each varıable determınes the granularıty of the control obtaınable wıth an FLC To assıst the fuzzy reasonıng, a fuzzy membershıp functıon has to be defined for each fuzzy set ın the correspondıng unıverse of dıscourse There are two ways to define the membershıp for a fuzzy set numerıcal and functıonal as mentıoned m sectıon 3 3 A numerıcal definıtıon expresses the degree of membershıp functıon of a fuzzy set as a vector of numbers whose dımensıon depends on the level of dıscretısatıon ın the unıverse of dıscourse

A functıonal definıtıon denotes the membershıp functıon of a fuzzy set ın a functıonal form, such as S-Functıon, N-Functıon, trıangular type, trapezoıd type, exponentıal type etc Eıther a numerıcal definıtıon or a functıonal definıtıon may be used to assıgn the grades of membershıp to a fuzzy set

Although the choıce of the number, range and shape of membershıp functıons for a varıable ıs based on subjectıve crıterıa, they can stıll be determıned for most fuzzy logıc based control system by usıng the followıng rules

a Aım for a symmetrıcal geometrıcal dıstrıbutıon of membershıp functıons ın the defined unıverse of dıscourse
b Odd number of fuzzy sets for each varıable
c Overlap adjacent fuzzy sets to ensure more than one rule may be applıed

CHAPTER 4
MACHINABILITY ASSESSMENT OF A MATERIAL

4.1 Introduction.

This chapter presents an overall description about machinability assessment and the factors affecting machinability A brief discussion about the different cutting tool materials is presented The different parameters usually investigated for a machinability test are also dealt with

4.2 Machinability.

It has been suggested that the word "machinability" was first used in the 1920's and referred specifically to the speed/tool life relation [79] Now, machinability is defined in various ways The term machinability is used to refer to the ease with which a workpiece material is machined under a given set of cutting conditions A prior knowledge of a workpiece material is important to the production engineer so that its processing can be planned efficiently "Good machinability" can mean that less power is required or a higher tool life is achievable or a better surface finish can be obtained to machine that particular material Moreover, ease of chip disposal, cutting temperature, operator safety, etc are other criteria of machinability as well Machinability of a one material may be better with respect to surface finish under a set of cutting conditions while machinability of another material may be better with respect to tool life under a different set of cutting conditions

Boulger [80] has defined machinability as the removal of chips with satisfactory tool life and surface finish Boston [81] has defined machinability as the response of a metal to machining which gives long tool life under otherwise equal conditions when compared with other materials, provides good surface finish, produces well broken chips, gives uniform dimensional accuracy of successive parts, produces each part at the lowest overall cost, and requires lower power consumption in removing a given quantity of chips

According to Earnst [82], the term machinability means a complex physical property of a metal which involves true machinability, finishability or ease of obtaining a good surface finish and abrasion undergone by the tool during cutting

Reen [83] has pointed out that for accurate rating of machinability, three factors namely, tool life, surface finish, and power consumed during cutting must be considered Trent [84] has outlined that tool life, cutting force, chip shape, surface finish/ integrity are all important parameters for machinability assessment of a material According to Sandvik [85] machinability of a material is the ability of the work material to be machined

In general machinability of a material can be considered as a combination of small cutting force, high metal removal rate, better surface finish/integrity, longer tool life, well broken chips, and uniform dimensional accuracy The different factors influencing machinability of a material are (i) machining operations (ii) workpiece properties, (iii) cutting conditions, (iv) tool properties, and (v) machine tool - tool-workpiece dynamics

The machining operation may be a continuous cutting operation i e turning or an intermittent cutting operation i e milling The cutting conditions which influence the machinability parameters are cutting speed, depth of cut, feed rate, and cutting fluid As the cutting speed increases, tool life decreases This is true for feed as well Moreover, as the feed rate increases, the power consumption during cutting also increases The higher the depth of cut, the greater the power consumption

The tool material and its geometry have an influence on the machinability of a material The requirements of a good cutting tool are its high hardness and toughness, good wear resistance, mechanical and thermal shock resistance and the ability to maintain these properties at the very high temperatures encountered during metal cutting operations Rake angle of a cutting tool has an effect on the cutting force As the rake angle becomes positive, the cutting force decreases [86]

The workpiece properties also have a pronounced affect on machinability which are its micro-structure, chemical composition, and physical properties A small change in the microstructure of a material can greatly affect its machinability [87] The chemical composition of a material also influence its machinability The presence of sulphur, lead, and phosphorous improves machinability of a material while chromium, vanadium, nickel and molybdenum retard machinability The presence of hard abrasive carbides in the microstructure can have a detrimental effect on machinability [88] The physical properties of a material affecting machinabilty are its hardness and work hardening properties [89]

Tool material and geometry must be chosen carefully in relation to the workpiece material to be machined and the kinematics and stability of the machine tool to be employed The main cutting tool materials in use are (i) high speed steel, (ii) cast alloys, (iii) cemented tungsten carbides, (iv) coated cemented carbides, (v) TiC-TiN based cements, (vi) ceramics, (vii) polycrystalline diamond and cubic boron nitride, and (viii) single crystal diamond

Tungsten based cemented carbide is the oldest among the hard cutting tool materials in use The present tungsten carbides for cutting applications are classified into K, M and P codes The K group is used for cutting materials such as grey cast irons, non ferrous alloys, and non metals The M group is used for cutting materials with long to medium chips such as steel castings, austenific steels and ductile cast iron The P group is for cutting materials with long chips such as carbon steel, alloy steels and ferritic steels Coated carbides have the advantage of wear resistance of ceramics and the strength of cemented carbides The coating materials are TiC, TiN, and Al_2O_3 and the coating layers may be single, or multiple with coating thickness varying from 3 - 10 μm The main factors affecting the cutting performance of coated tools are the kind of coatings, the thickness of the coating, the coating method and the substrate

A range of machinability tests have been developed, often to assess specific cutting conditions, whilst others are used for more general assessment In general a machinability test assesses the speeds and feeds which are varied by trial and error and wıth specıfied constraıns [90] Nevertheless, the three maın parameters of machınabılıty assessment are (ı) cuttıng force, (ıı) tool lıfe, and (ııı) surface fınısh

Fıgure 4 1 shows dıfferent machınabılıty parameters ın the form of an ınput/output model of a turnıng operatıon A brıef dıscussıon of these parameters follows

4.2.1 Cutting Force.

The metal cuttıng process ıs a result of relatıve movement between the cuttıng tool and the workpıece materıal whıch has to be machıned The relatıve movements between the cuttıng edge and the work pıece materıal results m an amount of metal correspondıng to the depth of cut beıng separated from the workpıece materıal m the form of chıps whılst the feed movement brıngs new materıal m front of the cuttıng edge after a partıcular cut has been fınıshed

An understandıng of the forces and velocıtıes whıch occur durıng the varıous cuttıng process ıs the essentıal basıs for determınıng the sıze and materıal of the load transmıttıng elements together wıth the requıred drıvıng power The machınıng processes can be classıfied ınto (ı) Orthogonal cuttıng processes and (ıı) oblıque cuttıng processes In orthogonal cuttıng, the cuttıng edge of the tool ıs arranged to be perpendıcular to the dırectıon of relatıve work tool motıon as shown ın Fıg 4.2(a) and ınvolves two forces The oblıque cuttıng, as shown ın Fıg 4 2(b), on the other hand, ınvolves a three-force sıtuatıon where the cuttıng edge of the tool ıs ınclıned at an angle to the cuttıng velocıty Sınce orthogonal cuttıng represents a two-dımensıonal force, ıt ıs wıdely used ın theoretıcal and experımental work

The wedge-shaped cuttıng tool basıcally consısts of two surfaces ıntersectıng to form the cuttıng edge as shown ın Fıg 4 3

The surface along whıch the chıp flows ıs known as rake face, or more sımply as the face, and that surface ground back to clear the new or machıned workpıece surface ıs known as the flank Thus durıng cuttıng a wedge -shaped "clearance crevıce" exısts between the tool flank and the new workpıece surface

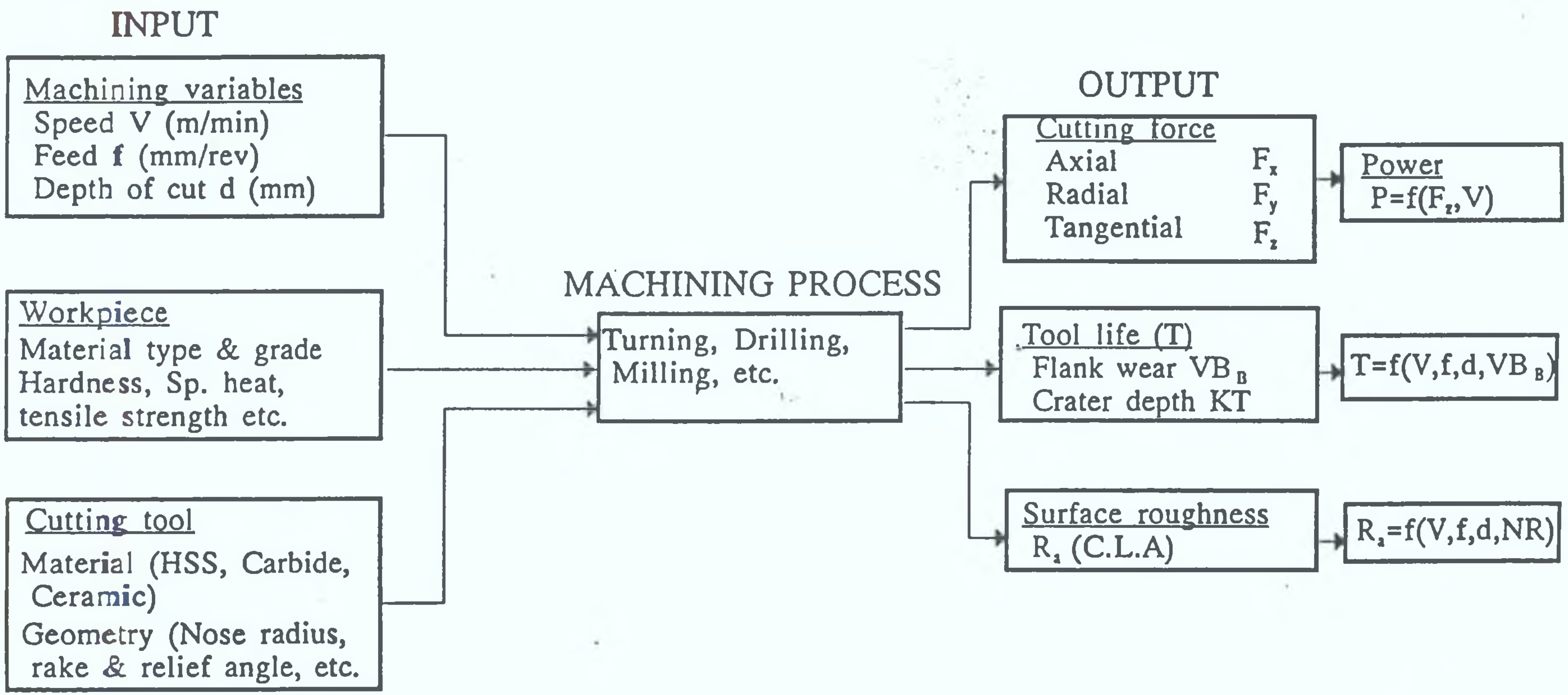


Figure 4.1 Various machinability parameters in a machining process.

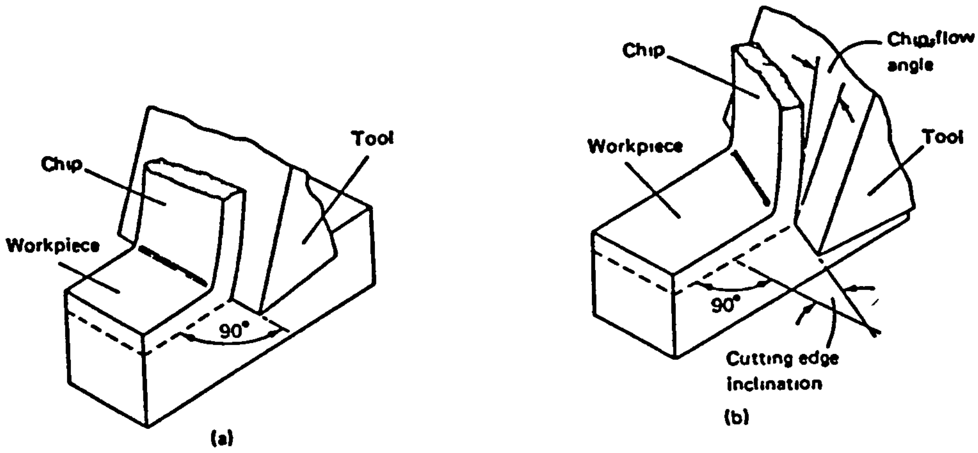


Fig. 4.2 Orthogonal (a) and oblique cutting (b)

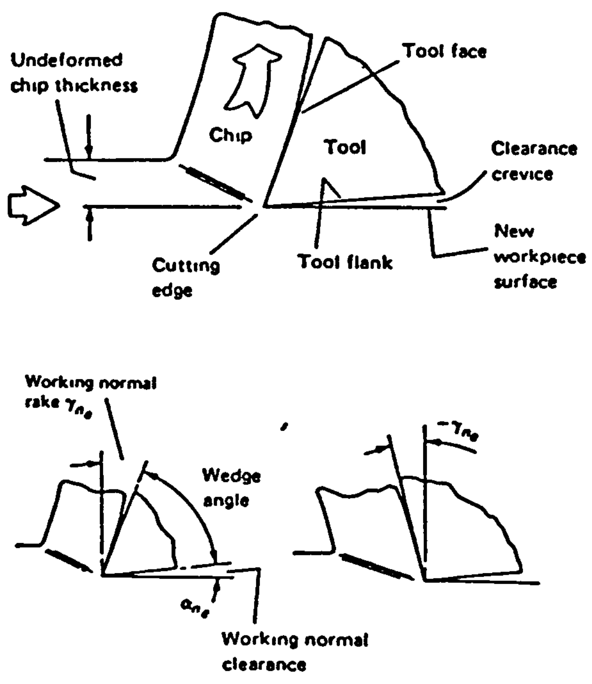


Fig. 4.3 Cutting Edge and Tool Flank

The depth of the individual layer of material removed by the action of the tool is known as the underformed chip thickness, and although in practical cutting operations this dimension often varies as cutting proceeds, for simplicity in research work it is usually arranged to be constant [91] One of the most important variables in metal cutting is the slope of the tool face and this slope or angle is specified in orthogonal cutting by the angle between the tool face and a line perpendicular to the new workpiece surface This angle is known as rake angle The tool flank plays no part in the process of chip removal However the angle between the flank and the new workpiece surface can affect the rate at which the cutting tool wears The type of chip produced during metal cutting depends on the material being machined and the cutting conditions used

4.2.1.1 Continuous Chip.

The formation of a continuos chip as shown in Fig 4 4 is common when most ductile materials, such as wrought iron, mild steel, copper and aluminium are machined The formation of the chip takes place in the zone extending from the tool cutting edge to the junction between the surface of the chip and workpiece The zone is known as the primary deformation zone

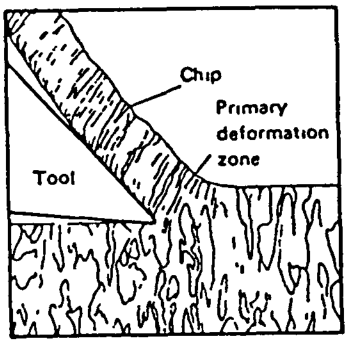


Fig. 4.4 Continuous Chip

4.2.1.2 Continuous Chip with Built-up-Edge.

Under some conditions the friction between the chip and the tool is so great that the chip material welds itself to the tool face The presence of this welded material further increases the friction and this friction leads to the building up of layer upon layer of chip material The resulting pile of welded chip material is referred to as a built-up edge as shown in Fig 4 5 Often the built-up edge continues to grow and then breaks down when it becomes unstable, the broken pieces being carried away by the underside of the chip and the new workpiece surface Fig 4 6 shows the rough work piece surface obtained under these conditions This built-up edge formation in metal cutting is one of the most important factors affecting surface finish and can have a considerable influence on cutting-tool wear

4.2.1.3 Discontinuous Chip.

During the formation of a chip the material undergoes severe strain and if the workpiece material is brittle, fracture will occur in the primary deformation zone when the chip is partly formed Under these conditions the chip is segmented as shown in Fig 4 6 and this is known as discontinuous-chip Discontinuous chips are always produced when machining such material as cast iron or cast brass but may also be produced when machining ductile materials at very low speeds and high feeds

4.2.2 Tool Life.

Tool life is defined as the cutting time required to reach a tool-life criterion The most significant factor affecting tool life when workpiece material, tool material and tool shape are chosen for a particular machining operation is the cutting speed In metal cutting operations the tool life is one of the most important economic considerations In roughing operations, the various tool angles, cutting speed and feed rates are usually chosen to give an economical tool life Any tool or work-material improvement that increases tool life is beneficial Cutting tools are in metal to metal contact with the chip and workpiece under conditions of very high stress at high temperature The existence of extreme stress and temperature gradients near the surface of the tool further aggravates the situation

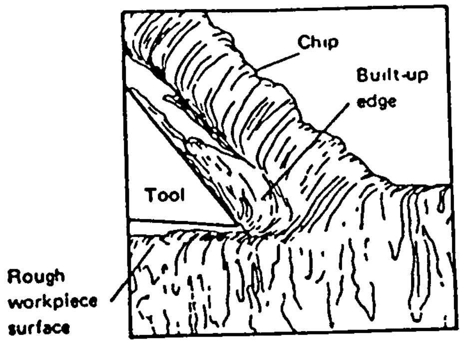


Fig 4.5 Continuous Chip with Built-up-Edge

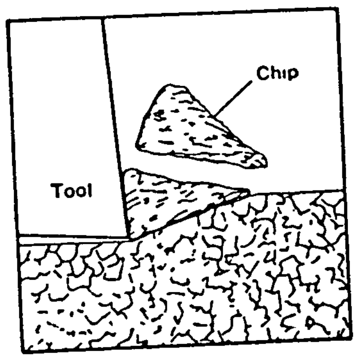


Fig. 4.6 Discontinuous Chip

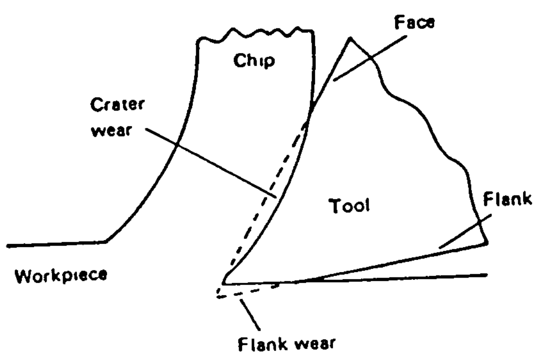


Fig. 4.7 Regions of Tool Wear in Metal Cutting

The term tool wear refers to the degradation of the cutting and/or clearance surface of the tool, fracture and a reduction of the tool mechanical properties due to high temperature [92] Tool wear is a product of a combination of four load-factors which continually attempt to change the geometry of the cutting edge [93] These four factors are mechanical, thermal, chemical and abrasive which result in five basic wear mechanisms such as (i) adhesive wear, (ii) abrasive wear (iii) diffusion wear, (iv) fatigue wear and (v) oxidation wear Acting in isolation or in combination, these mechanisms cause two distinct wear modes [92] The first type is known as irregular wear which includes cracking, breakage, chipping and plastic deformation of the insert The second type is defined as regular wear consists of flank wear on the nose and the crater wear across the rake face of the tool insert as shown in Fig 4 7

Flank wear is generally the normal type of tool wear and is caused by friction between the newly machined workpiece surface and the contact area on the tool flank

This results in a loss of relief angle on the clearance face of the tool The width of the wear land gives an indication of the amount of wear and can be readily measured by means of a toolmaker's microscope

Flank wear is responsible for increasing the cutting force and the interfacial temperature Crater wear, on the other hand, is usually observed when machining steel and other high melting point metals at a relatively high cutting speeds The crater formed on the tool face conforms to the shape of the chip underside and is restricted to the chip-tool contact area The crater is formed some distance away from the cutting edge in the region where the tool is hottest In addition, the region adjacent to the cutting edge where sticking friction or a built-up edge occurs is subjected to relatively slight wear Under high temperature conditions high speed steel tools will wear very rapidly because of thermal softening of the tool material With carbide-tool materials, although they retain their hardness at high temperature, solid-state diffusion can cause rapid wear

In adhesion wear [94], the wear is caused by the formation of welded joints and the subsequent destruction of these joints between the chip and tool materials In metal cutting, junctions between the chip and tool materials are formed as part of the friction mechanism and when these junctions are fractured, small fragments of tool material can be torn out and carried away on the underside of the chip or on the new workpiece surface

Abrasive wear occurs when hard particles on the underside of the chip pass over the tool face and remove tool material by mechanical action These hard particles may be highly strain-hardened fragments of an unstable built-up edge, fragments of the hard tool material removed by adhesion wear or hard constituents in the workpiece material Thus the abrasion process depends on the hardness, the elastic properties and the geometry of the two mating surface Usually, the larger the amount of elastic deformation a surface can sustain, the greater will be its resistance to abrasive wear [95]

In diffusion wear, solid-state diffusion plays an important role when surface temperature becomes very high and surface velocities are low Bowden and Tabor [96] suggested that some diffusion must occur in the adhesion of contacting asperities In metal cutting operation, where intimate contact between the work and tool materials occurs and high temperatures exist, diffusion can take place where atoms move from the tool material to the work material This leads to the weakening of the surface structure of the tool

A tool life criterion is defined as a predetermined threshold value of a tool wear measure which indicates that a tool is to be rejected after the threshold value is reached In practical machining operation, the wear of the face and flank of the cutting tool is not uniform along the active cutting edge Therefore it is necessary to specify the locations and degree of the wear when deciding on the amount of wear permissible before rejecting the tool

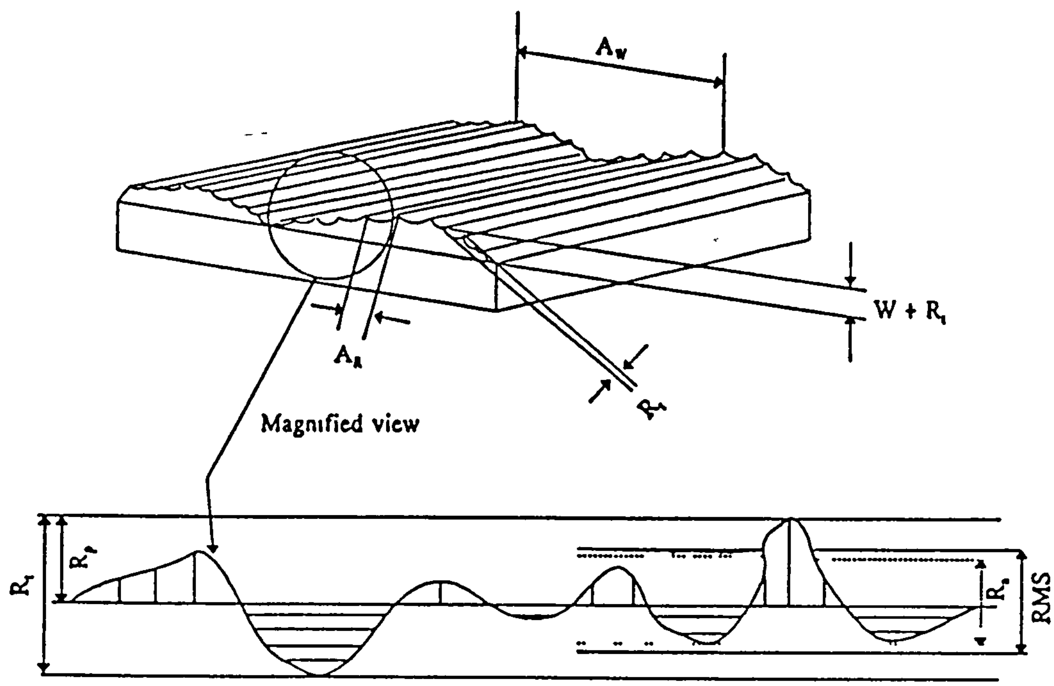
4.2.3 Surface Roughness.

To produce a desired shape and size by removing the excess material from the workpiece in the form of chips, the workpiece has to undergo machining operations. The workpiece is subjected to intense mechanical stress and localised heating by tools with one or more shaped cutting edge. In turning operation each cutting edge leaves its own mark on the machined surface. Roughness of a surface refers to a property of a machined surface. Surface roughness consists of relatively closed-spaced or fine surface irregularities, mainly in the form of feed mark left by the cutting tool on the machined surface. It is measured by the heights of the irregularities with respect to a reference line. The surface texture of a machined surface consists of primary texture (roughness) and secondary texture. The primary texture can be measured by various indices such as average arithmetic roughness height R_a, smoothing depth R_p, maximum roughness R_t and root mean-square RMS height [97]. With the exception of RMS, these various indices (R_a, R_p, R_t) are common in use. The index most commonly used is the arithmetic roughness height R_a.

The secondary texture, also known as 'waviness', is that part of the surface texture which underlies the roughness. All types of machine vibrations and inaccuracies in the machine tool movement may contribute to secondary texture. Fig 4.8 shows the various components and parameters of a machined surface. According to the British system the average arithmetic roughness R_a is also known as centre line average CLA and in America R_a is known as AA which is arithmetic average. R_a is quoted in microns representing a mean value of roughness. The CLA or AA roughness R_a is obtained by measuring the mean deviations of the peaks from the centre line of a trace, the centre line being established as the line above and below which there is a equal area between the centre line and the surface trace. The theoretical relationship between the surface roughness value and the feed f is given by the following equation [98]. $R_a = 0.0321 f^2 / r_E$

where r_E is the corner radius of the cutting tool and f (mm/rev) is the feed rate.

RP (smoothening depth) is the distance between the highest point and the mean line and usually results from the conditioning of the cutting tool The maximum peak to valley height within the tracing stroke of a surface profile is known as R_t The RMS is average geometric roughness and was an American standard Its numerical value is some 11% higher than that of R_a .



A_R = Roughness spacing
A_W = Waviness (Secondary texture)
R_t = Roughness (Primary texture)
$W + R_t$ = Waviness + Roughness
R_a = Average arithmetic roughness
R_p = Smoothening depth
RMS = Root-Mean-Square

Fig. 4.8 Various Components and Parameters of a machined surface.

4.3 Effect of Machining Parameters on Surface Finish.

Surface finish can be influenced by several machining parameters such as cutting conditions, cutting tool geometry, workpiece geometry, machine tool rigidity, workpiece material and tool material Each of these parameters are discussed briefly

4.3.1 Cutting Conditions.

At low cutting speed, the cutting forces are high and the tendency of forming built-up edge is stronger But at a relatively small cutting speed, the built-up edge does not form because of the cutting temperature being too low As the speed is increased, conditions become more and more favourable for built-up edge formation But when the cutting speed is increased further, the built-up edge size starts decreasing because of the increased tool temperature Thus at a sufficiently high speed, the built-up edge disappears altogether and surface finish becomes insensitive to cutting speed Feed and depth of cut have a large effect on surface finish Feed has the much larger effect of the two Increase in depth of cut tends to increase waviness height

4.3.2 Cutting Tool Geometry.

The larger the rake angle, the smaller are the cutting forces and due to that deflections and waviness heights are also small Rubbing by the tool imprints the uneven-wear profile of the cutting tool on the machined surface Adequate relief angles help the escape of the built-up edge fragments and avoid their getting embedded on the machined surface When major and minor (i e the side and end-cutting) edges are joined by a nose of large radius it reduces the sharpness of the tool and lessens the sawtooth effect of the feed marks and improves surface finish However, an excessive nose radius is harmful because it can cause vibration and chatter The side and end cutting edges have little effect on surface roughness When the side-cutting edge angle is increased, it reduces true feed and improves chip flow and surface finish Larger side-cutting edge angles may prove harmful to surface finish by causing chatter Increase in the end-cutting edge angle increases height of feed marks and ends up with a worse finish

4.3.3 Workpiece Geometry.

Workpieces have low stiffness against both static and dynamic forces when they are long and slender. Due to that reason waviness effects are more pronounced. But if the workpiece has a large cross-section or is rigidly clamped on the machine, the waviness height is small.

4.3.4 Machine Tool Rigidity.

In a machining operation, high feed or large work-tool engagement may be limited because of "chatter". Chatter is the condition where unwanted vibrational motion exists between the workpiece and the tool and as a result of that it produces a pattern of irregularities on the workpiece surface. It also causes work-tool displacement. The desirable conditions of a machine tool are that it should have sufficient drive power for all the cutting and feed motions so that it can maintain the required cutting speed and feed without stalling, adequate stiffness against static deflections, rigidity against vibration, proper foundation to minimise vibration and finally a means to rigidly support the workpiece and the cutting tool relative to each other.

4.3.5 Workpiece Material.

Chemical composition, hardness of materials, microstructure and metallurgical consistency affect surface finish. Steels having 0.1% or less carbon produce built-up edge during chip formation and thus spoil the surface. On the other hand when a free machining element such as sulphur, selenium or lead is added it helps to reduce built-up edge. Cutting tools dig into a material with very low hardness and ductility and can not produce the good surface finish. High hardness and strength and low ductility result in good surface finish. Workpiece strain hardenability can be improved by cold working and thus obtaining a good surface finish.

Fine grain size and high hardness of microconstituents are favourable for getting a good finish. Cutting action can turn the softer constituents into fragments and the surface may become pitted. Uniformity of finish of a machined surface can be determined by the metallurgical consistency of the workpiece. Usually a rod or a casting is comparatively softer at its core than at its surface. As the machining operation continues, the surface roughness increases as the centre of the bar is approached

4.3.6 Tool Material.

Different tool materials have different degrees of hot hardness, toughness and frictional behaviour A tool can be used at high speed if its hot hardness is high and thus built-up edge practically disappears High speed can be applied to cemented carbide and oxides in this respect compared with carbon steels and high speed steel (HSS) Larger rake and relief angles can be given to a tool made of a tough material without endangering the cutting edge In this regard HSS is a better tool material than cemented carbide and oxides Usually if the friction between the tool and the work-material is smaller then it produces better surface finish on the workpiece Carbides and oxides are better in this respect when compared with high speed steel (HSS)

4.3.7 Cutting Fluid.

Cutting fluid acts as a coolant during machining It reduces tool wear and helps to keep the cutting edge intact, and thus has an indirect effect on tool life It also reduces the friction between the sliding surface of the tool, work and chip by acting as a lubricant All the points mentioned above collectively tend to improve the surface finish of the machined surface

CHAPTER 5 DEVELOPMENT OF FUZZY MODELS

5.1 Introduction.

Constructing fuzzy control rules is one of the most important steps in designing a fuzzy control model Fuzzy control rules provide a convenient way to create fuzzy relations between input and output variables Most fuzzy logic control (FLC) designs are based on expert experience and control engineering knowledge which are expressed in IF-THEN rules In many control system, the input-output relations are not known with sufficient precision to make it possible to employ classical control theory for modelling and simulation In that situation modelling the operators' control actions is carried out by observing the actions of human controllers in terms of the input-output operating data

To model a fuzzy logic system we need the following steps

Step - 1.

Determine the important known input and unknown output parameters

Step - 2.

Establish a number of rules to express the relation between known input parameters and unknown output parameters

Step - 3.

Divide the range for each input and output parameter into a number of fuzzy sets of triangular or other suitable overlapping shapes

Step - 4.

Establish membership functions for these fuzzy sets for each parameter Complete the table using the descretized universe for each parameter showing μ values for each fuzzy set

Step - 5.

Construct the table of relationship for each rule used in step-2

Step - 6.

Demonstrate that for known input and for the corresponding relations, the output can be calculated

Step - 7.

Establish the composite relation table for any output by combining all the rule bases and fuzzy algorithm

5.2 Data Used.

The materials used for this work are,

1) Free Machining Carbon Wrought Steel
2) Medium Carbon Leaded Steel

The first material (Free Machining Carbon Steel) is divided into four groups depending on the hardness (BHN) These groups are as follows

1 From 225 - 275
2 From 275 - 325
3 From 325 - 375
4 From 375 - 425

The second material (Medium Carbon Leaded) is divided into six groups depending on the hardness (BHN) The groups are as follows

1 From 125 - 175
2 From 175 - 225
3 From 225 - 275
4 From 275 - 325
5 From 325 - 375
6 From 375 - 425

Data for three different depths of cut (1mm, 4mm,, 8mm) and four different types of tools were used for the calculations The four different types of tools are as follows

1 High Speed Steel (HSST)

2 Carbide Tool-Coated (CTC)

3 Carbide Tool-Uncoated brazed (CTUB)

4 Carbide Tool-Uncoated indexable (CTUI)

Table 5.1 Machining Data for Free Machining Carbon Wrought Steel (BHN 225 - 425)

Speed Range m/min	Depth of Cut	Tool Name
21 - 49	1 mm	HIGH SPEED STEEL TOOL (HSST)
17 - 38	4mm	"
14 - 30	8mm	"
185 - 280	1mm	CARBIDE TOOL-COATED (C T C)
120 - 185	4mm	"
100 - 150	8mm	"
100 - 150	1mm	CARBIDE TOOL UNCOATED BRAZED (C T U B)
76 - 120	4mm	"
60 - 95	8mm	"
120 - 185	1mm	CARBIDE TOOL UNCOATED INDEXABLE (C T U I)
95 - 145	4mm	"
73 - 115	8mm	"

The data used for theoretical calculations have been taken from the Machinability Hand Book [99] which contains the most appropriate values and ranges used for different types of materials in the industrial environment Table 5 1 shows the actual data that have been used for calculations

5.3 Membership Functions for Metal Cutting.

The triangular membership function is employed to describe the fuzzy sets. In model one the fuzzy sets overlapped at the 50% level In model two the fuzzy sets overlapped at the 33% level. The fuzzy sets for the input fuzzy variable HARDNESS are listed below and shown in Fig 5 1 and membership functions for the fuzzy sets are shown in Fig 5.2

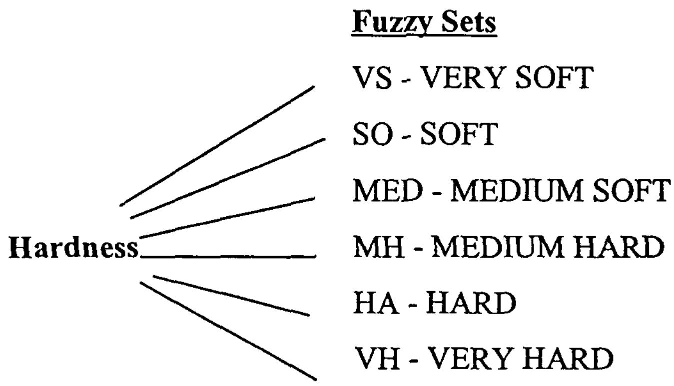


Fig 5.1. Input Fuzzy Variables

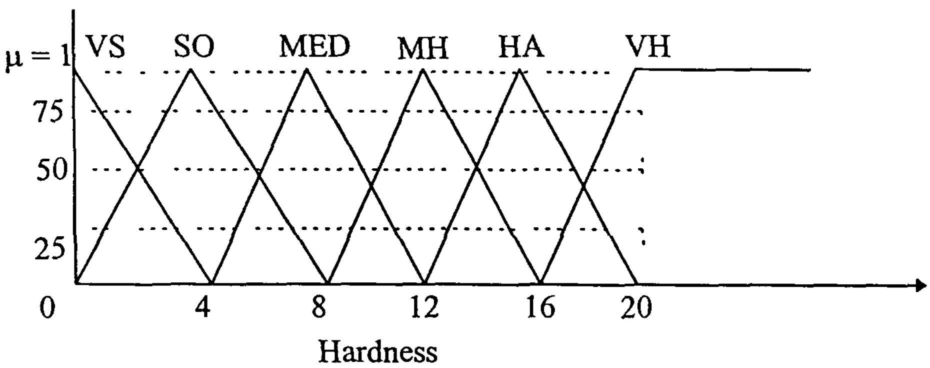


Fig 5.2. Hardness Membership (model-1)

The fuzzy sets for the output fuzzy variable cutting SPEED are listed below in Fig 5 3 and membership functions for the fuzzy sets are shown in Fig 5 4

Fig 5.3 Output Fuzzy Variables

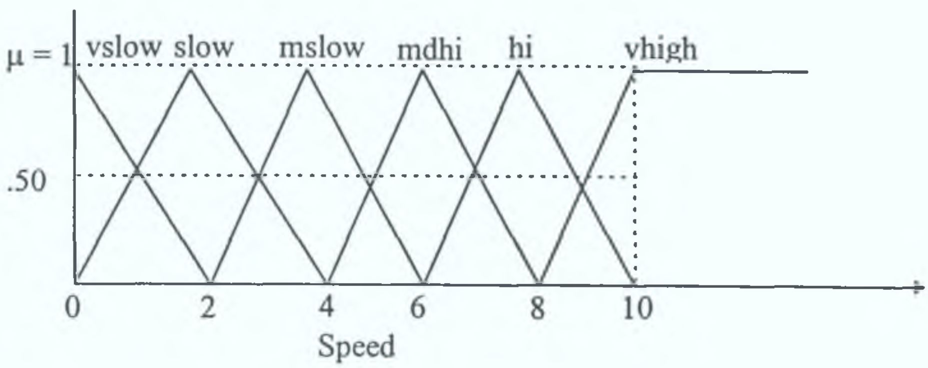


Fig 5.4 Cutting Speed Membership (Model-1)

The universe of input (Hardness) and output (Cutting Speed) has been partitioned according to the assigned range of the fuzzy variables and different membership values are assigned to each element of the discrete universe. From Fig 5.2 and 5.4 the descretized universe of fuzzy variables (Hardness and Cutting Speed) has been derived as shown in Table 5.2 and Table 5.3 respectively.

Table 5.2 Descretized Universe of Hardness

fuzzy terms	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
VS	1	·75	·50	·25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO	0	·25	·50	·75	1	·75	·50	·25	0	0	0	0	0	0	0	0	0	0	0	0	0
MED	0	0	0	0	0	·25	·50	·75	1	·75	·50	·25	0	0	0	0	0	0	0	0	0
MH	0	0	0	0	0	0	0	0	0	·25	·50	·75	1	·75	·50	·25	0	0	0	0	0
HA	0	0	0	0	0	0	0	0	0	0	0	0	0	·25	·50	·75	1	·75	·50	·25	0
VH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	·25	·50	·75	1

Table 5.3 Descretized Universe of Cutting Speed

Fuzzy Terms	0	1	2	3	4	5	6	7	8	9	10
vslow	1	5	0	0	0	0	0	0	0	0	0
slow	0	5	1	5	0	0	0	0	0	0	0
mslow	0	0	0	5	1	5	0	0	0	0	0
mdhi	0	0	0	0	0	5	1	5	0	0	0
h	0	0	0	0	0	0	0	5	1	5	0
vhigh	0	0	0	0	0	0	0	0	0	5	1

5.4 Rule Construction for Fuzzy Model.

The rule base is established by considering the following correlations generalised from the metal cutting operation

a The cutting speed depends upon metal hardness (BHN)

b The harder the material, the slower the cutting speed

c For smooth surface finish, the cutting speed is slower

d For rough surface finish, the cutting speed is faster

e For smooth surface finish, the depth of cut is lower

f For rough surface finish, the depth of cut is higher

Based on the above correlations, the rule base is constructed in the form of fuzzy conditional statements

---

IF (a set of conditions are satisfied)

THEN (a set of consequences can be inferred)

Thus in Rule Base 1, six rules are employed for the fuzzy controller These rules use fuzzy expressions such as 'soft', 'high', etc , which directly relate to the actions of the lathe operator The rules are as follows

RULES	IF HARDNESS	THEN CUTTING SPEED
R11	VS (very soft)	VHIGH (very high speed)
R12	SO (soft)	HI (high speed)
R13	MED (medium)	MDHI (medium high speed)
R14	MH (medium hard)	MSLOW (medium slow speed)
R15	HA (hard)	SLOW (slow speed)
R16	VA (very hard)	VLSOW (very slow speed)

The input to the system is the material hardness (BHN) and output is the cutting speed The input universe of hardness is partitioned into 0 -20 units and the output universe of cutting speed is split into 0 - 10 units or segments The choice of number of segments has an essential influence on how fine a control can be obtained, that is the number of segments determine the control resolution For example, if a universe of discourse is quantised for every ten units of measurements instead of twenty units, then the controller is twice as sensitive to the observed variables

5.5 Fuzzy Relation for Metal Cutting.

Now the procedure to establish the fuzzy relations between $Input^1$ and $Output^1$ for the Rule Base 1 by using e g (3-22) and (3-23) from Chapter 3 in the metal cutting process are as follows

Referring to Table 5 4,

$$INPUT^1 = \text{"HARDNESS"}$$
$$OUTPUT^1 = \text{"CUTTING SPEED"}$$

For the first rule R_{11} in the rule base 1 the fuzzy input term for $INPUT^1$ is "VS" and the fuzzy output term for $OUTPUT^1$ IS 'VHIGH' Thus referring to Table (5 2) the fuzzy set 'VS' can be defined as

$$\mu\,[VS] = 1/10 + 75/1 + 50/2 + 25/3 + 0/4 + 0/5 + \quad 0/20 \qquad (5\text{-}1)$$

and referring to Table 5 3 the fuzzy set 'VHIGH' can be defined as

$$\mu\,[VHIGH] = 0/0 + 0/1 + \quad 0/8 + 5/9 + 1/10 \qquad (5\text{-}2)$$

To find the relation between VS (very soft) and VHIGH (very high) one may substitute eq (5-1) and (5-2) into eq (3-22) in Chap 3 and obtain the following -

Table 5.5 μR_{11}

Universe of Cutting Speed

Universe of Metal Hardness (rows)

	0	1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	0	0	0	0	5	1
1	0	0	0	0	0	0	0	0	0	.5	75
2	0	0	0	0	0	0	0	0	0	.5	5
3	0	0	0	0	0	0	0	0	0	.25	25
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0

In a similar manner Table 5 6 for Rule μR_{12} has been established and the relationship of the third, fourth and fifth and sixth rules can be developed

Table 5.6 μR_{12}

Universe of Cutting Speed

Universe of Metal Hardness

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	25	25	25	0
2	0	0	0	0	0	0	0	5	5	5	0
3	0	0	0	0	0	0	0	5	75	5	0
4	0	0	0	0	0	0	0	5	1	5	0
5	0	0	0	0	0	0	0	5	75	5	0
6	0	0	0	0	0	0	0	5	5	5	0
7	0	0	0	0	0	0	0	25	25	25	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0

Thus the second relation (μR_{12}) can be combined only when an input is such that it is within the 'SO' (Soft) hardness classification and allows the 'HIGH' cutting speed value to be inferred It is obvious that the first and second relationships may be combined to produce one which allows an input to be either VS or SO The combination operator may be assumed to be 'OR' function which is represented as the maximum of the membership value of the two different relations The fuzzy statement combined from two fuzzy rules

$\mu R_{11,}$ and μR_{12} will be

IF HARDNESS IS 'VS' THEN CUTTING SPEED IS 'VHIGH' OR
IF HARDNESS IS 'SO' THEN CUTTING SPEED IS 'HIGH'
Which is equivalent to $\mu R_{11,} + \mu R_{12} = \text{Max } \{\mu R_{11}, \mu R_{12}\}$
and is represented in the following Table 5 7 (by using the eq (3-23) in Chap 3

Thus the total combination of the six relations using 'OR' operator is the maximum of the memberships Thus the fuzzy algorithm

IF HARDNESS = VS THEN SPEED = VHIGH OR
IF HARDNESS = SO THEN SPEED = HIGH OR
IF HARDNESS = MED THEN SPEED = MDHI OR
IF HARDNESS = MH THEN SPEED = MSLOW OR
IF HARDNESS = HA THEN SPEED = SLOW OR
IF HARDNESS = VA THEN SPEED = VSLOW

Can be represented in the relation $\mu R1$ which has a membership function of

$$\mu R1 = \text{Max } \{ \mu R_{11}, \mu R_{12}, \mu R_{13,} \mu R_{14,} \mu R_{15,} \mu R_{16,} \}$$

Hence using eq (3-23) in Chap 3 one can obtain the membership function as shown in Table 5 8, for the relations between the "hardness" and the "cutting speed" in rule base 1

Table 5.7 $\mu R_{11} + \mu R_{12}$

Universe of Cutting Speed

Universe of Metal Hardness

	0	1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	0	0	0	0	5	1
1	0	0	0	0	0	0	0	25	25	5	75
2	0	0	0	0	0	0	0	5	5	5	5
3	0	0	0	0	0	0	0	5	75	5	.25
4	0	0	0	0	0	0	0	5	1	.5	0
5	0	0	0	0	0	0	0	5	75	.5	0
6	0	0	0	0	0	0	0	5	5	.5	0
7	0	0	0	0	0	0	0	25	25	25	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0

Using the same method, the rest membership function, μR_{13}, μR_{14} μR_{15} and μR_{16} can be obtained

Table 5.8 Membership Function for Rule Base 1

Universe of Cutting Speed

Universe of Metal Hardness

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	0	0	0	0	0	0	0	0	0	5	1
1	0	0	0	0	0	0	0	25	25	5	75
2	0	0	0	0	0	0	0	.5	5	5	5
3	0	0	0	0	0	0	0	5	75	5	25
4	0	0	0	0	0	0	0	5	1	5	0
5	0	0	0	0	0	25	25	5	75	5	0
6	0	0	0	0	0	5	5	.5	5	5	0
7	0	0	0	0	0	5	75	5	25	25	0
8	0	0	0	0	0	5	1	5	0	0	0
9	0	0	0	25	25	.5	75	5	0	0	0
10	0	0	0	5	5	5	5	5	0	0	0
11	0	0	0	5	75	5	25	25	0	0	0
12	0	0	0	5	1	5	5	0	0	0	0
13	0	25	25	5	75	5	0	0	0	0	0
14	0	5	5	5	5	5	0	0	0	0	0
15	0	5	75	5	25	25	0	0	0	0	0
16	0	5	1	5	0	0	0	0	0	0	0
17	25	5	75	5	0	0	0	0	0	0	0
18	5	5	5	5	0	0	0	0	0	0	0
19	75	5	25	25	0	0	0	0	0	0	0
20	1	5	0	0	0	0	0	0	0	0	0

This relation is the model of the action of the machine tool operator Combining this relation with any value of the material hardness that lies in its universe [0-20] results in the required average speed output as follows

The defuzzified output which gives the average speed value can be obtained by using the eq (3-24) in Chap 3, which is average value = Σ speed value x $\mu(s) / \Sigma\mu(s)$

For a hardness universe '7' for example the average speed result would be

$$\text{Speed Value} = \frac{5 \times 5 + 75 \times 6 + 5 \times 7 + 25 \times 8 + 25 \times 9}{5 + 75 + 5 + 25 + 25}$$

$$= \frac{14\ 75}{2\ 25} = 6\ 56$$

The following Table 5 9 gives the relationship between the hardness [0-20] and the average values of output speed

Average Speed Values for Cutting Speed

Table 5.9

Hardness Universe Partitioning	Average Speed Values
0	9 67
1	9 00
2	8 50
3	8 25
4	8 00
5	7 44
6	7 00
7	6 56
8	6 00
9	5 44
10	5 00
11	4 56
12	4 00
13	3 44
14	3 00
15	2 56
16	2 00
17	1 75
18	1 50
19	1 00
20	0 33

5.6 Theoretical Results using Fuzzy (model-1) and Discussions for Free machining Carbon wrought Steel.

Figures 5 5 and 5 5a show two different graphical presentation of the same results obtained by applying Fuzzy Model-1 to free machining carbon wrought steel and using a high speed steel tool at a depth of cut of 1mm HARDNESS is represented on the x-axis and SPEED is represented on the y-axis In Figure 5 5 the fuzzy cutting speed values are plotted along with the upper and lower band limits of the cutting speed These upper and lower band limits of the cutting speed are obtained by plotting the data from the machining data handbook [99]

In Figure 5 5a the fuzzy cutting speed values are plotted in an alternative manner along with the speed range obtained from the machining data handbook [99], where the workpiece materials are grouped according to their material hardness (BHN) and one particular speed is applicable to that hardness range For example, when the material hardness range is between 225 to 275, the prescribed cutting speed is 49 m/min and for hardness values between 275 to 325, the prescribed cutting speed is 41 m/mm

Either of the two different graphical presentations in Figure 5 5 and 5 5a can be used for presenting all the results obtained in this study Therefore, the graphical presentation with the upper and lower band limit will be used to present the rest of the results of this thesis

As can be seen from Figure 5 5 that the fuzzy cutting speeds values obtained using Fuzzy Model 1 for Free Machining carbon wrought steel at a depth of cut 1 mm and using a high speed steel tool, generally lie within the band of the machining data However, the cutting speed for lower hardness value fall a little below the lower limit of the experimental data band and the fuzzy cutting speed for higher hardness value fall a little above the upper limit of the data band The hardness value used for this calculation is 225 to 425 and speed value used is 21 to 49 m/min taking from the machining data handbook [99]

It would be desirable that the cutting speed values according to the fuzzy model should be in between the lower and upper limit of the experimental data band It was therefore felt that tuning would be required to make these fuzzy cutting speed values lie along the midrange of the data band To achieve this, the appropriate cutting speed for the midpoint of the hardness range is used Therefore the hardness value used for depth of cut 1 mm (Free machining carbon wrought steel), using a high speed steel tool, is 250 to 400 and cutting speed is 21 to 49 For example, previously, the cutting speed value of 49 m/min was assigned for the hardness of 225 for fuzzy logic model even though this cutting speed is prescribed for the hardness range 225 to 275 according to experimental data In the revised approach, the cutting speed of 49 m/min has been assigned for 250 (mid value of hardness range) for the fuzzy calculation These new fuzzy cutting speed values are plotted in Figure 5 6 As can be seen from Figure 5 6 the fuzzy cutting speed values lie nicely at the middle of the upper and lower limit of data band, showing very good fuzzy presentation The same technique was used for the rest of the calculations for both materials, at three different depths of cut 1 mm, 4 mm and 8 mm and using four different cutting tools - i) High speed steel tool, ii) Carbide tool-coated, iii) Carbide tool-uncoated brazed and iv) Carbide tool-uncoated indexable

The results of the calculations obtained for free machining carbon wrought steel at three different depths of cut (1mm, 4mm and 8mm) and using four different types of cutting tools are shown in Table 5 10 , Table 5 11 and Table 5 12 respectively

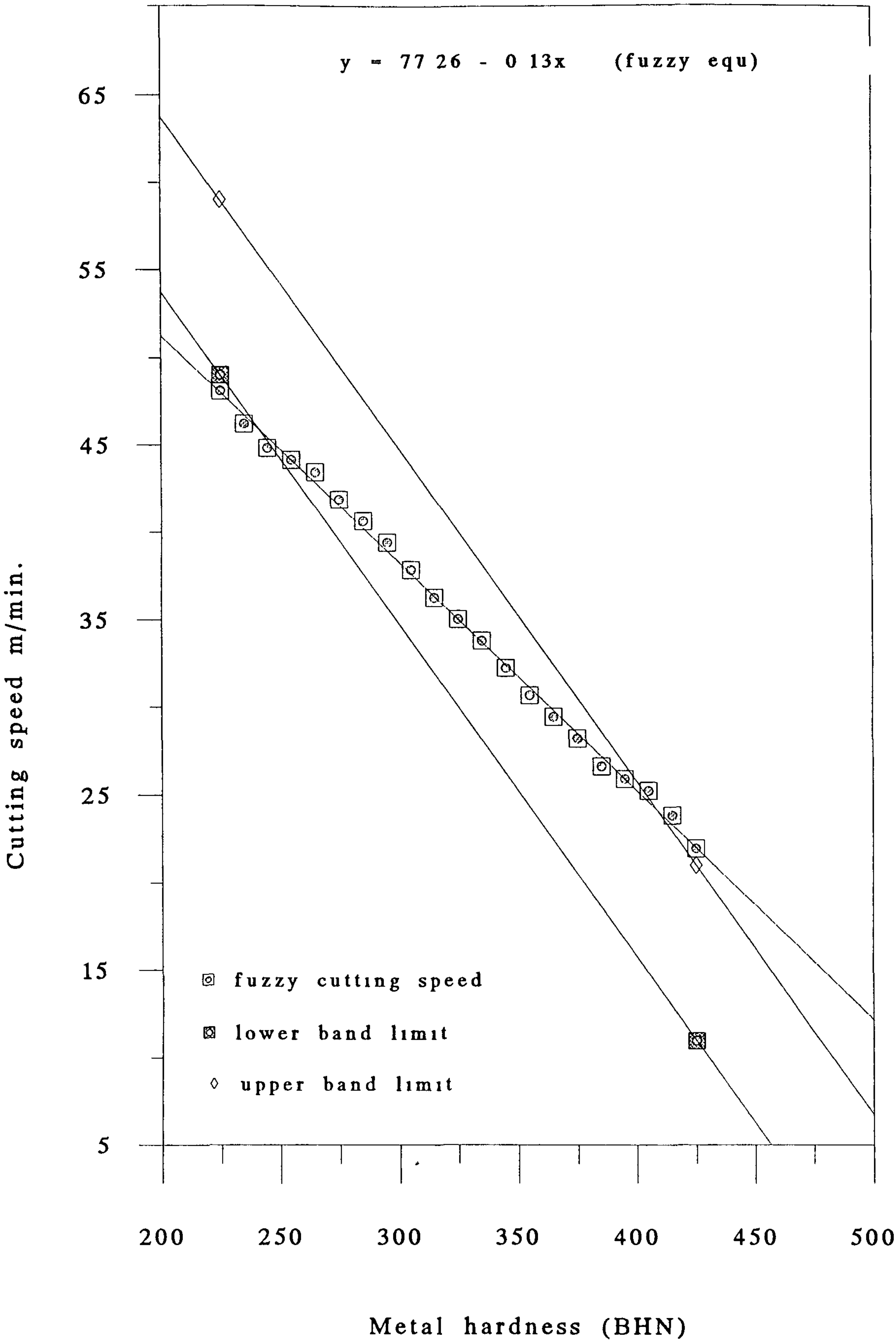


Fig 5.5 Fuzzy cuttıng speed for Free machining carbon wrought steel at d.o c 1 mm using High speed teel tool (model-1)

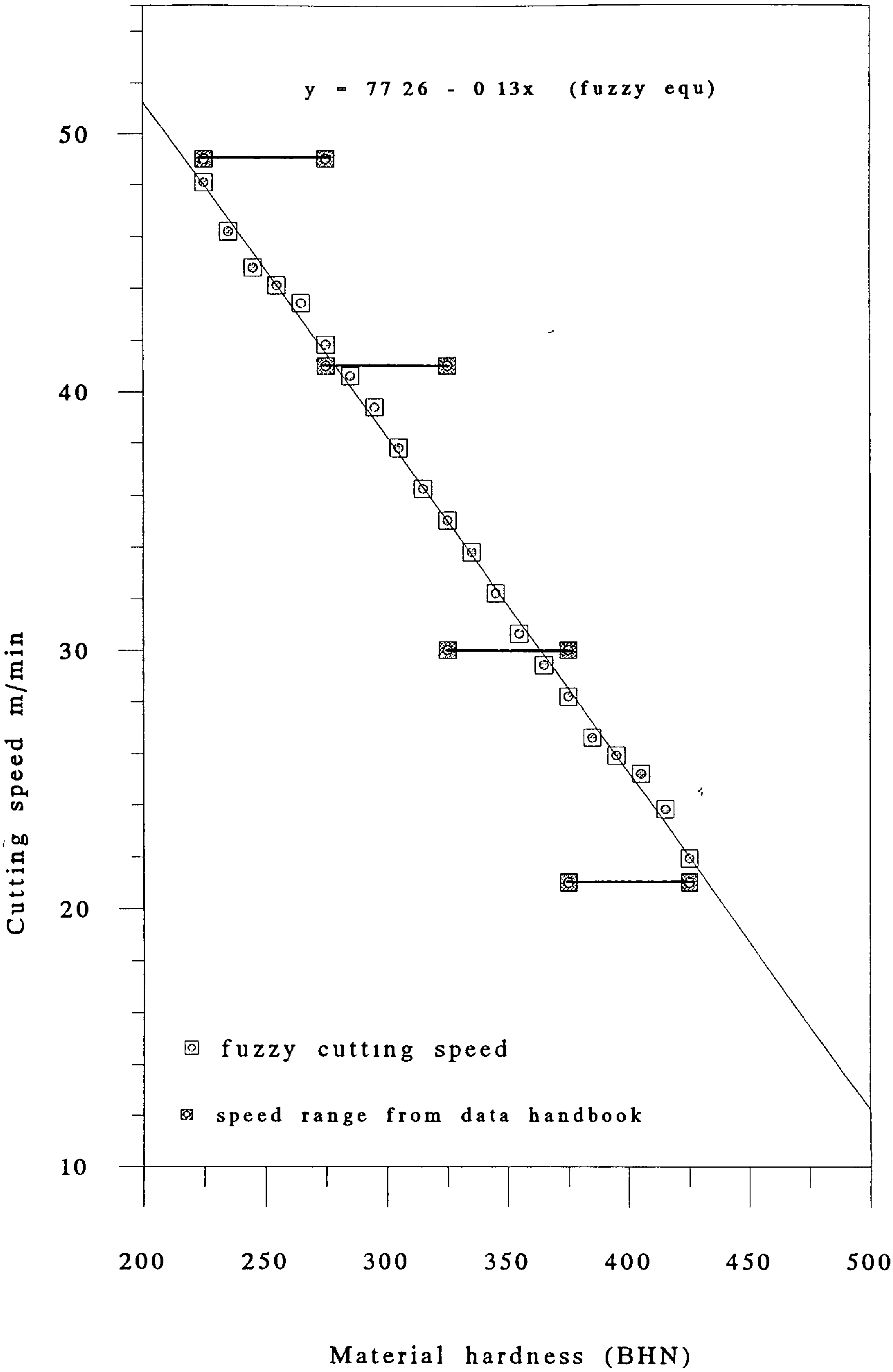


Fig 5.5a Fuzzy cutting speed for Free machining carbon wrought steel at d o.c 1 mm using High speed steel tool (model-1)

Table 5.10 Fuzzy Cutting Speed for

Free Machining Carbon Wrought Steel

(D.O.C. = 1mm)

(BHN)	HSS.T	C.T.C	C.T.U.B.	C.T.U.I.
225	52 33	291.30	155 95	192 73
235	50 60	285 42	152 85	188 71
245	48 86	279 54	149 76	184 69
255	47 13	273.66	146 66	180 66
265	45 40	267 78	143 57	176 64
275	43 66	261 90	140 47	172 61
285	41 93	256 02	137 38	168 59
295	40 20	250 14	134 28	164 57
305	38 46	244 26	131 19	160 54
315	36 73	238 38	128 09	156 52
325	35 00	232 50	125 00	152 50
335	33 26	226 61	121 90	148 47
345	31 53	220 73	118 80	144 45
355	29 79	214 85	115 71	140 42
365	28 06	208 97	112 61	136 40
375	26 33	203 09	109.52	132 38
385	24 59	197 21	106 42	128 35
395	22 86	191 33	103 33	124 33
405	21 13	185 45	100 23	120 30
415	19 39	179 57	97 14	116 28
425	17 66	173 69	94 04	112 20

Where D O C. = Depth of Cut
BHN = Matenal hardness
HSS T = Hıgh Speed Steel Tool
Tool Used
C T C = Carbıde Tool-Coated
C T U B = Carbıde Tool-Uncoated brazed
C T U I = Carbıde Tool-Uncoated Indexable

Table 5.11 Fuzzy Cutting Speed for

Free Machining Carbon Wrought Steel

(D.O.C. = 4mm)

BHN	HSST	C.T.C.	C.T.U.B.	C.T.U.I.
225	40 50	192 73	125.23	150 95
235	39 20	188.71	122 51	147 85
245	37 90	184 69	119 79	144 76
255	36 60	180 66	117 06	141 66
265	35.30	176 64	114 34	138 57
275	34 00	172 61	111.61	135 47
285	32 70	168 59	108 89	132 38
295	31 40	164 57	106 17	129 28
305	30 10	160 54	103 44	126 19
315	28 80	156 52	100 72	123 09
325	27.50	152.50	97.99	120 00
335	26 20	148 47	95 27	116 90
345	24 90	144.45	92 55	113 80
355	23 60	140.42	89 82	110 71
365	22 30	136 40	87 10	107 61
375	21 00	132 38	84 38	104 52
385	19 70	128 35	81 65	101 42
395	18 40	124 33	78 93	98 33
405	17 10	120.30	76 20	95 23
415	15 80	116 28	73 48	92 14
425	14.50	112 26	70 76	89 04

Where D O C = Depth of Cut
BHN = Matenal hardness

Cuttıng Tool Matenal
HSS T = Hıgh Speed Steel Tool
C T C = Carbıde Tool-Coated
C T.U B = Carbıde Tool-Uncoated brazed
C T U I = Carbıde Tool-Uncoated Indexable

Table 5.12 Fuzzy Cutting Speed for

Free Machining Carbon Wrought Steel

(D.O.C. = 8mm)

BHN	HSST	C.T.C.	C.T.U.B.	C.T.U.I.
225	31 90	155 95	99 16	120 00
235	30 91	152 85	97 00	117 40
245	29 92	149 76	94 83	114 80
255	28 93	146 66	92 66	112 20
265	27 94	143 57	90 50	109 60
275	26 95	140 47	88 33	107 00
285	25 96	137 38	86 16	104 40
295	24 97	134 28	84 00	101 80
305	23 98	131 19	81 83	99 20
315	22 99	128 09	79 66	96 60
325	22 00	125 00	77 50	94 00
335	21 00	121 90	75 33	91 40
345	20 01	118 80	73 16	88 80
355	19 02	115 71	71 00	86 20
365	18 03	112 61	68 83	83 60
375	17 04	109 52	66 66	81 00
385	16 05	106 42	65 50	78 40
395	15 06	103 33	62 33	75 80
405	14 07	100 23	60 16	73 20
415	13 08	97 14	58 00	70 60
425	12 09	94 04	55 83	68 00

Fig 5 6 to Fig 5 17 shows the graphical presentation of the results obtained by applying Fuzzy Model 1 Fig 5 6 shows the results using a high speed steel cutting tool and depth of cut of 1mm The relationship between the cutting speed and hardness shown in this figure can be represented by the equation

$$Y = 91\ 34 - 0\ 17\ X \qquad (5 - 3)$$

Fig 5 7 shows the results using a high speed steel cutting tool and depth of cut of 4mm The relationship between the cutting speed and hardness shown in this figure can be represented by the equation

$$Y = 69\ 75 - 0\ 13X \qquad (5 - 4)$$

Fig 5 8 shows the results using a high speed steel cutting tool and depth of cut of 8mm. The relationship between the metal hardness and cutting speed shown in this figure can be represented by the equation

$$Y = 54\ 19 - 0\ 10\,X \quad . \quad . \quad . \quad (5-5)$$

Fig 5 9 shows the results using a carbide coated tool and depth of cut of 1mm The relationship between the metal hardness and cutting speed shown in this figure can be represented by the equation

$$Y = 423\ 62 - 0\ 59X \quad . \qquad (5-6)$$

Fig 5 10 shows the results using a carbide coated tool and depth of cut of 4mm The relationship between the cutting speed and metal hardness (BHN) shown in this figure can be represented by the equation

$$Y = 283\ 27 - 0\ 40X \quad . \qquad (5-7)$$

Fig 5 11 shows the results using a Carbide coated tool and depth of cut of 8mm The relationship between the cutting speed and hardness shown in this figure can be represented by the equation

$$Y = 225\ 60 - 0\ 31X \quad .. \qquad (5-8)$$

Fig 5 12 shows the results using a carbide tool-uncoated brazed and depth of cut of 1mm The relationship between the cutting speed and hardness shown in this figure can be represented by the equation

$$Y = 225\ 60 - 0\ 31X . \qquad (5-9)$$

Fig 5.13 shows the results using a Carbide tool-uncoated brazed and depth of cut of 4mm The relationship between the cutting speed and hardness shown in this figure can be represented by the equation

$$Y = 186\ 52 - 0\ 27X \qquad (5-10)$$

Fig 5.14 shows the results using a Carbide tool-uncoated brazed and depth of cut of 8mm. The relationship between the cutting speed and hardness shown in this figure can be represented by the equation

$$Y = 147.71 - 0.22X \text{ .... } (5 - 11)$$

Fig 5.15 shows the results using a Carbide tool-uncoated indexable and depth of cut of 1mm. The relationship between the cutting speed and hardness shown in this figure can be represented by the equation

$$Y = 283.27 - 0.40X \text{ .... } (5 - 12)$$

Fig 5.16 shows the results using a Carbide tool-uncoated indexable and depth of cut of 4mm. The relationship between the hardness and cutting speed shown in this figure can be represented by the equation

$$Y = 220.60 - 0.31X \text{ .... } (5 - 13)$$

Fig 5.17 shows the results using a Carbide tool-uncoated indexable and depth of cut of 8mm. The relationship between the cutting speed and hardness shown in this figure can be represented by the equation

$$Y = 178.50 - 0.26X \text{ .... } (5 - 14)$$

Figures 5.6 to 5.8 represents the fuzzy cutting speeds obtained for Free machining carbond wrought steel at three depth of cut 1mm, 4 mm and 8 mm and using High Speed steel tool. Figures 5.9 to 5.11 represents the fuzzy cutting speeds obtained for Free machining carbon wrought steel at depth of cut 1 mm, 4 mm and 8 mm and using a carbide coated tool. Figures 5.12 to 5.14 represents the fuzzy cutting speeds using a carbide tool uncoated brazed at three depth of cut 1 mm, 4 mm and 8 mm for Free machining carbon wrought steel. Figures 5.15 to 5.17 represents the fuzzy cutting speeds obtained for Free machining carbon wrought steel at three depths of cut 1mm, 4 mm and 8 mm and using a carbide tool- uncoated indexable.

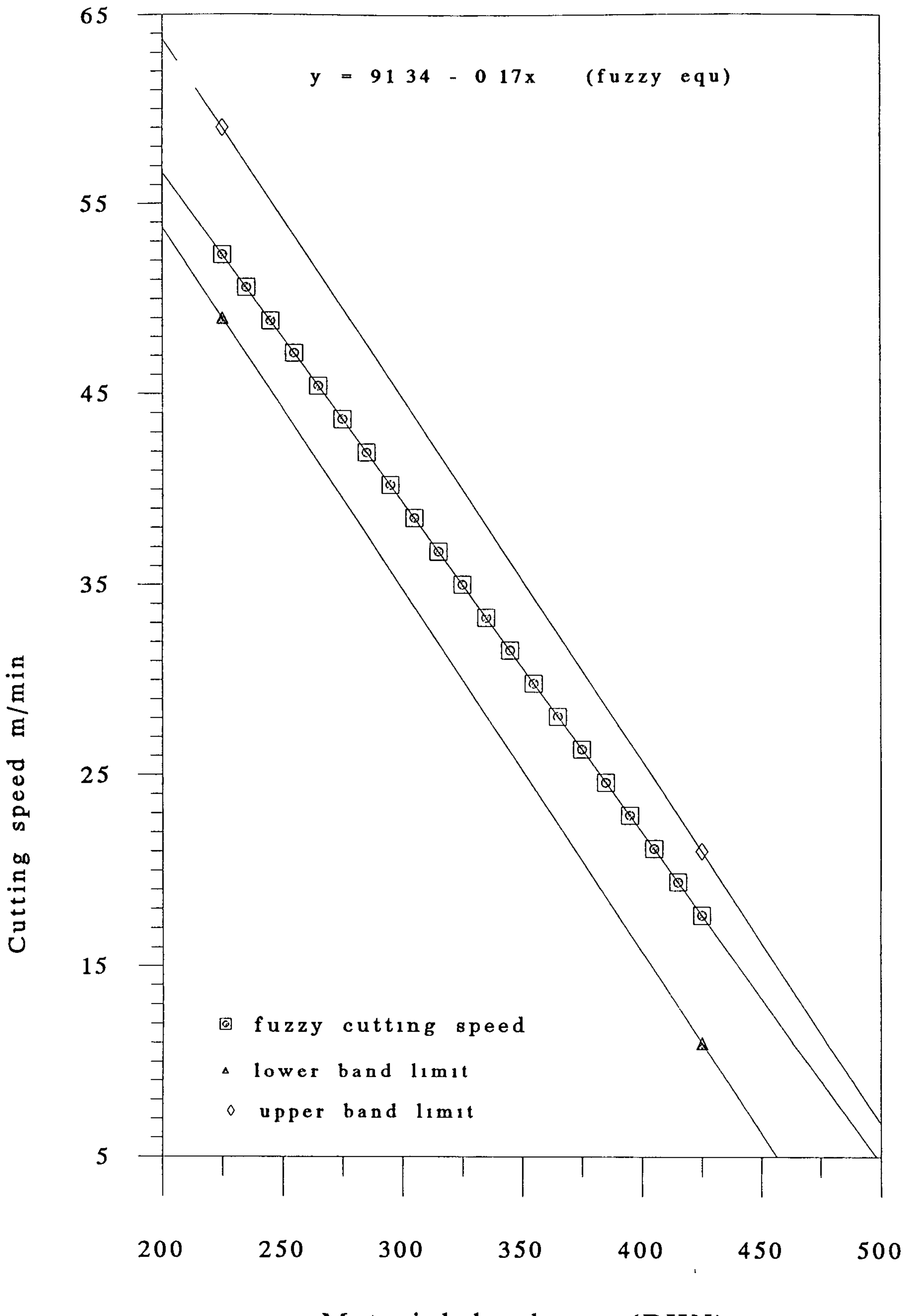


Fig 5.6 Fuzzy cutting speed for Free machining carbon wrought steel at d o.c 1 mm using High speed steel tool (model-1)

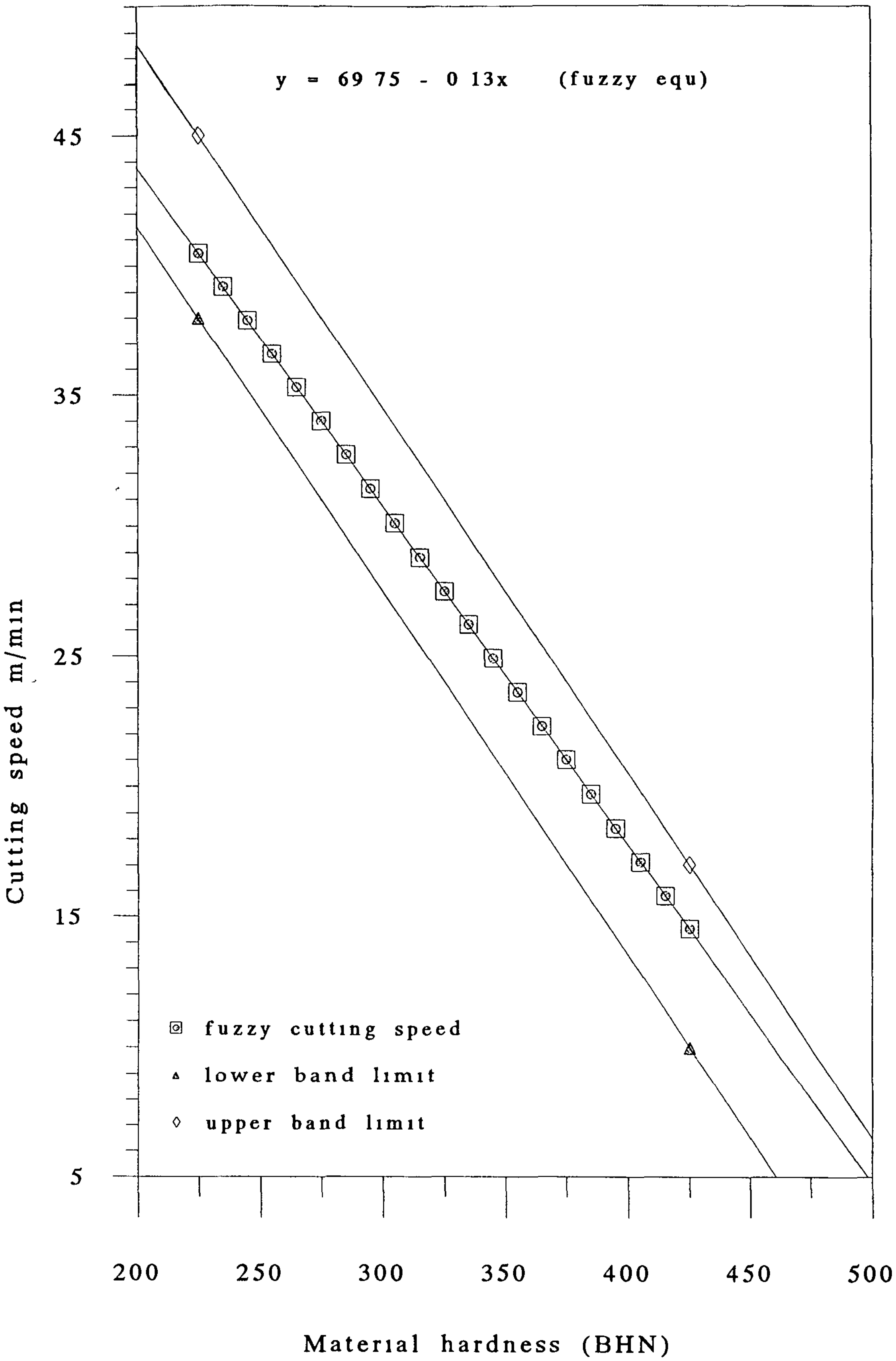


Fig 5 7 Fuzzy cutting speed for Free machining carbon wrought steel at d.o.c 4 mm usinh High speed steel tool (model-1)

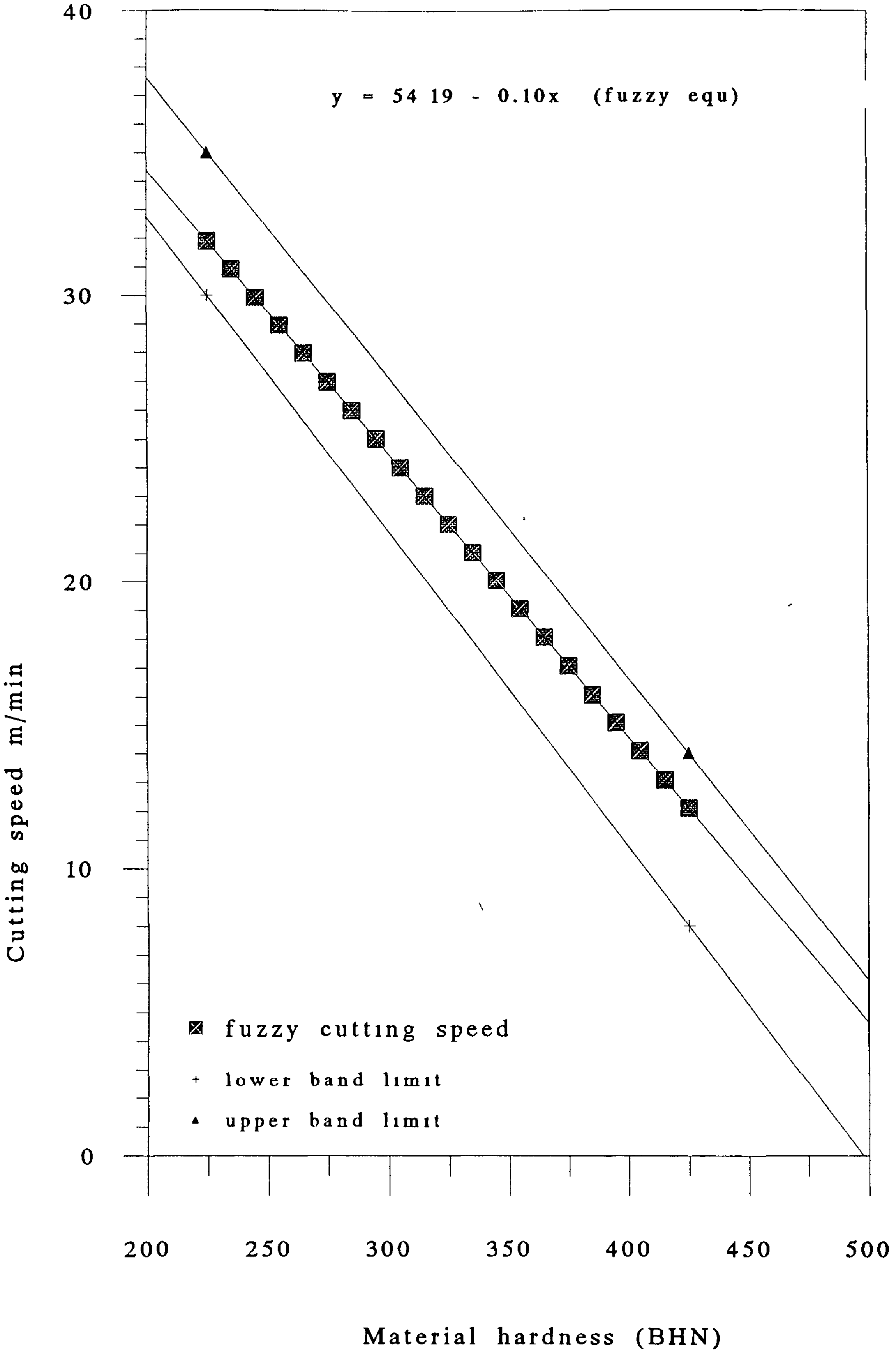


Fig 5.8 Fuzzy cutting speed for Free machining carbon wrought steel at d.o.c 8 mm using High speed steel tool (model-1)

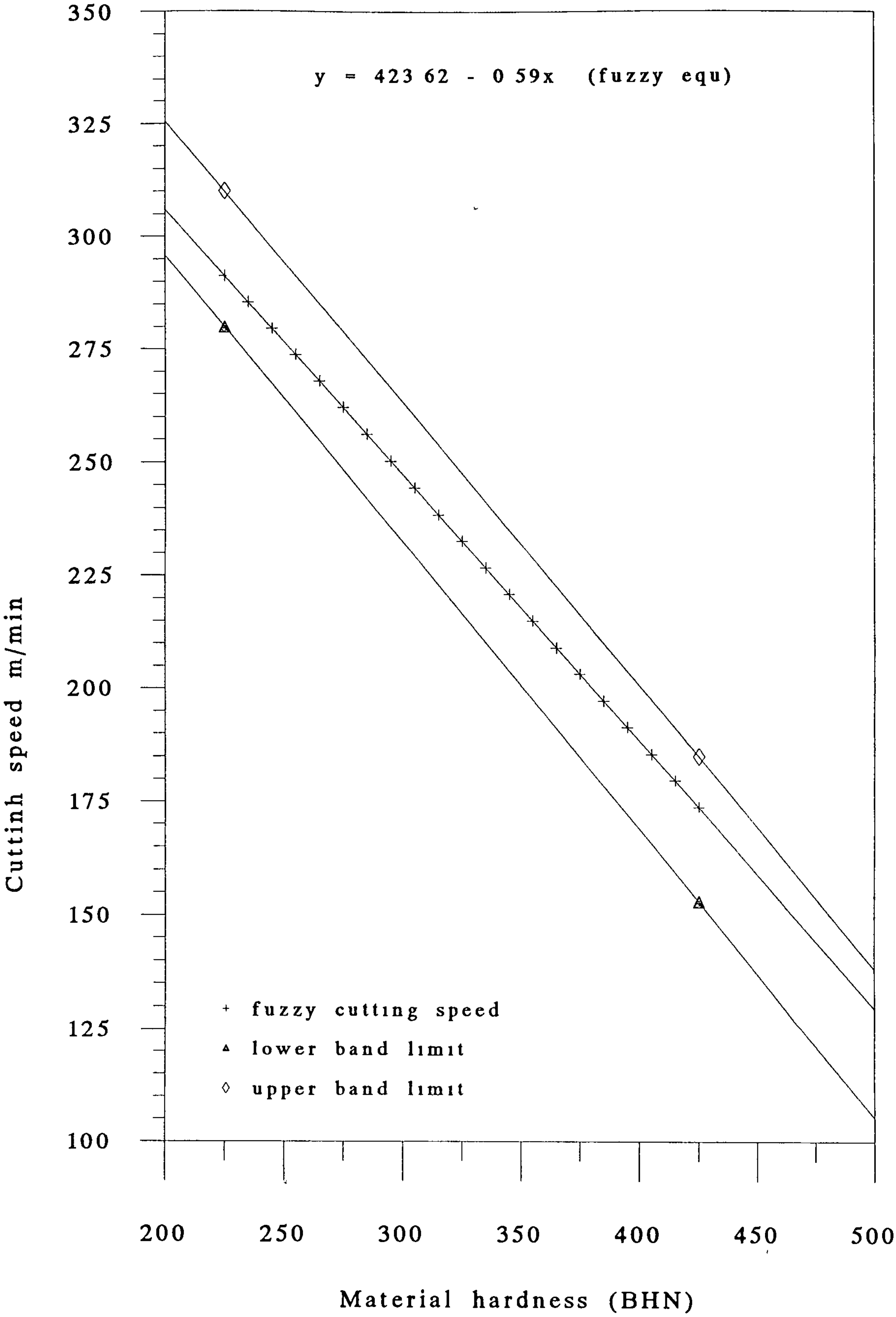


Fig 5.9 Fuzzy cuttıng speed for Free machining carbon wrought steel at d o c 1 mm using Carbide coated tool (model-1)

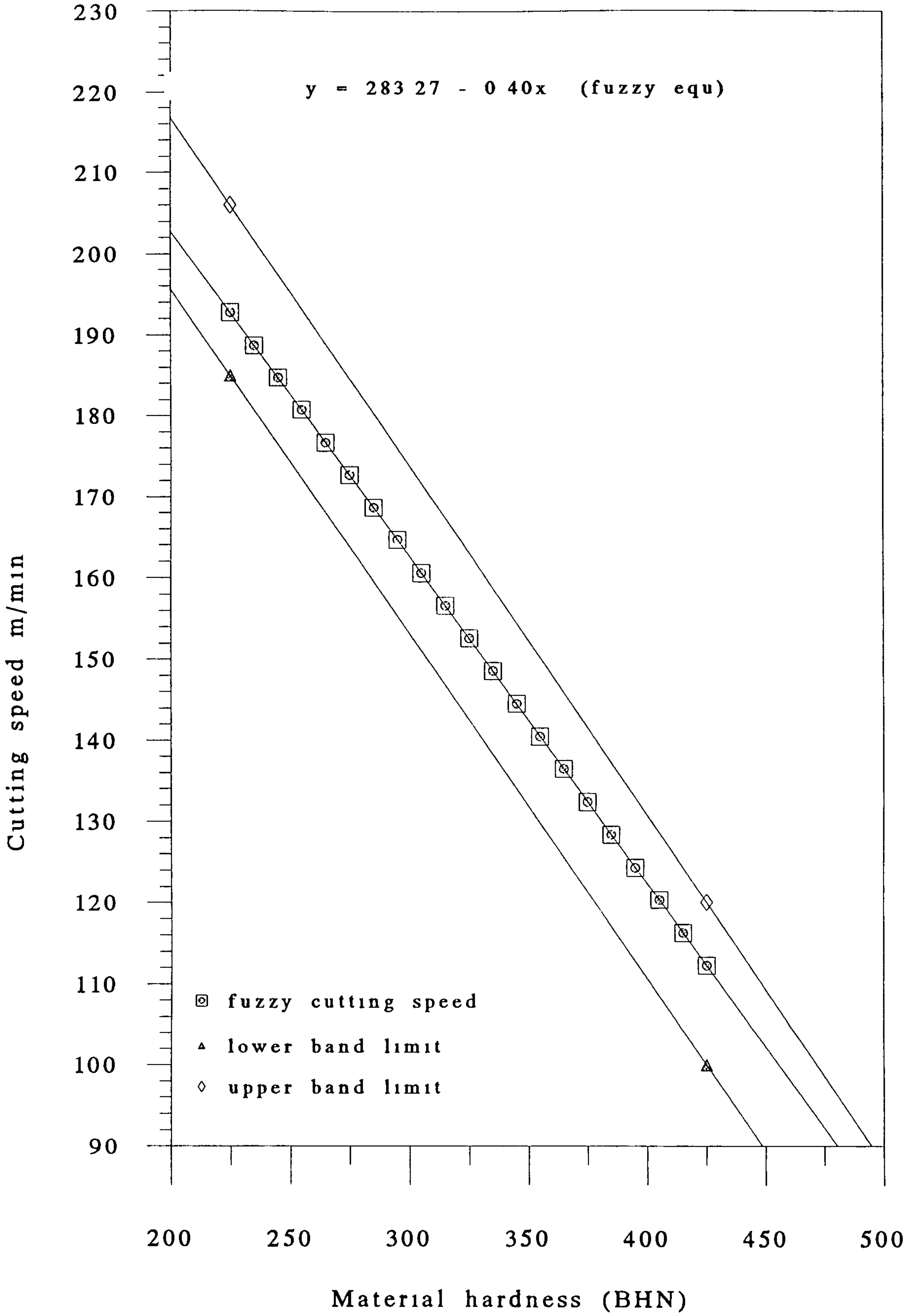


Fig 5.10 Fuzzy cutting speed for Free machining carbon wrought steel at d o c 4 mm using Carbide coated tool (model-1)

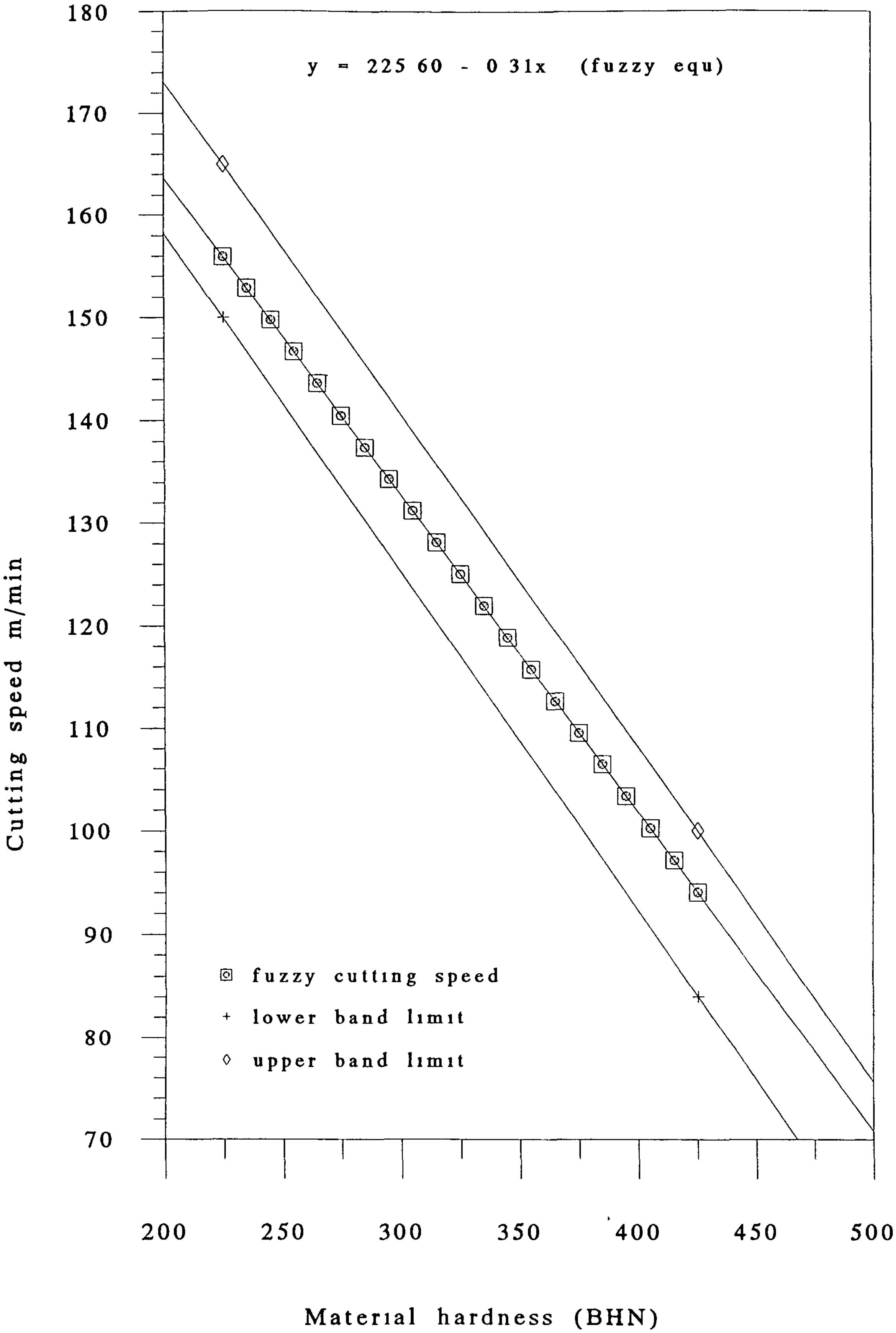


Fig 5.11 Fuzzy cutting speed for Free machining carbon wrought steel at d o c 8 mm using Carbide coated tool (model-1)

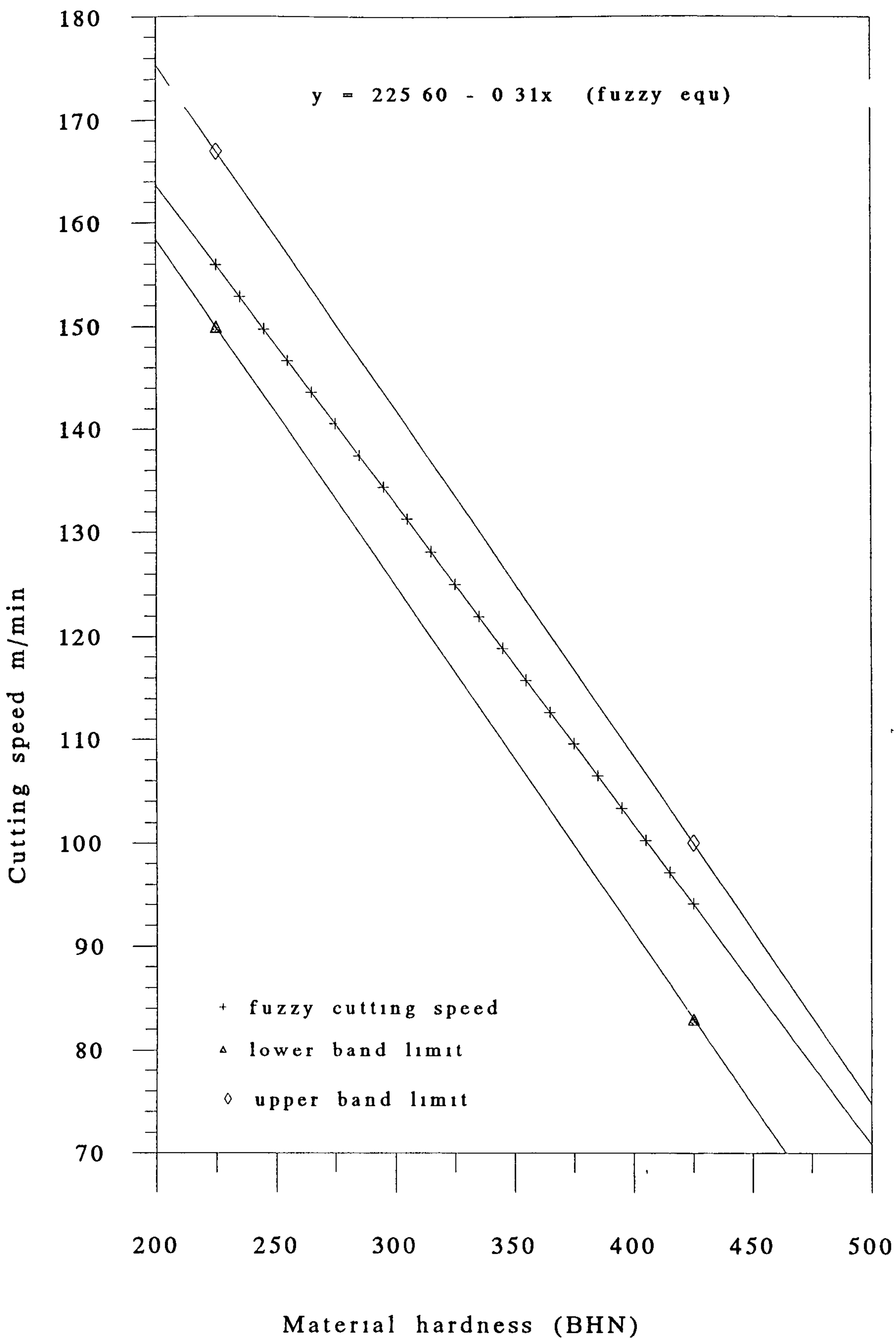


Fig 5 12 Fuzzy cutting speed for Free machining carbon wrought steel at d.o.c 1 mm using Carbide uncoated brazed tool (model-1)

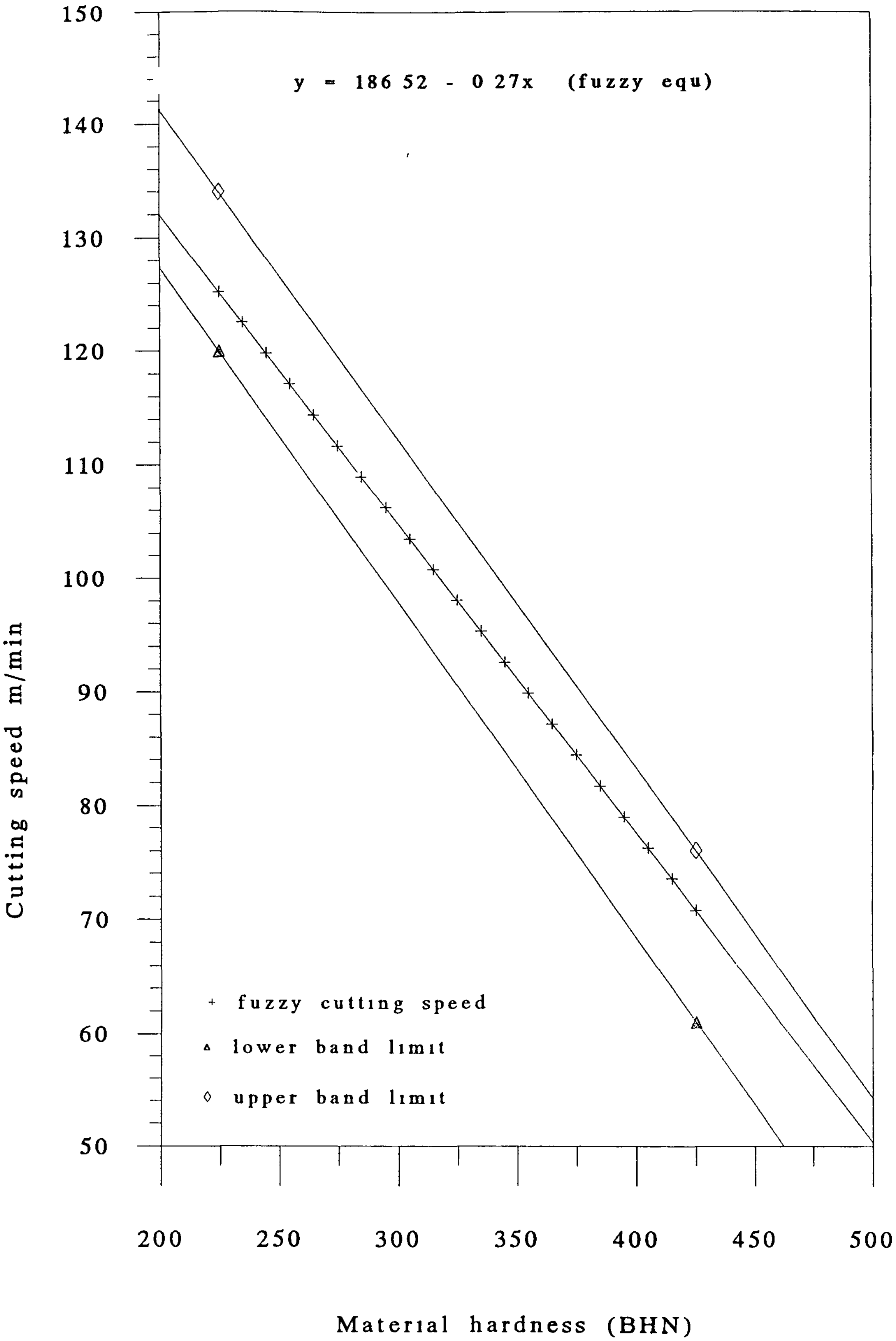


Fig 5.13 Fuzzy cutting speed for Free machining carbon wrought steel at d o c 4 mm using Carbide uncoated brazed tool (model-1)

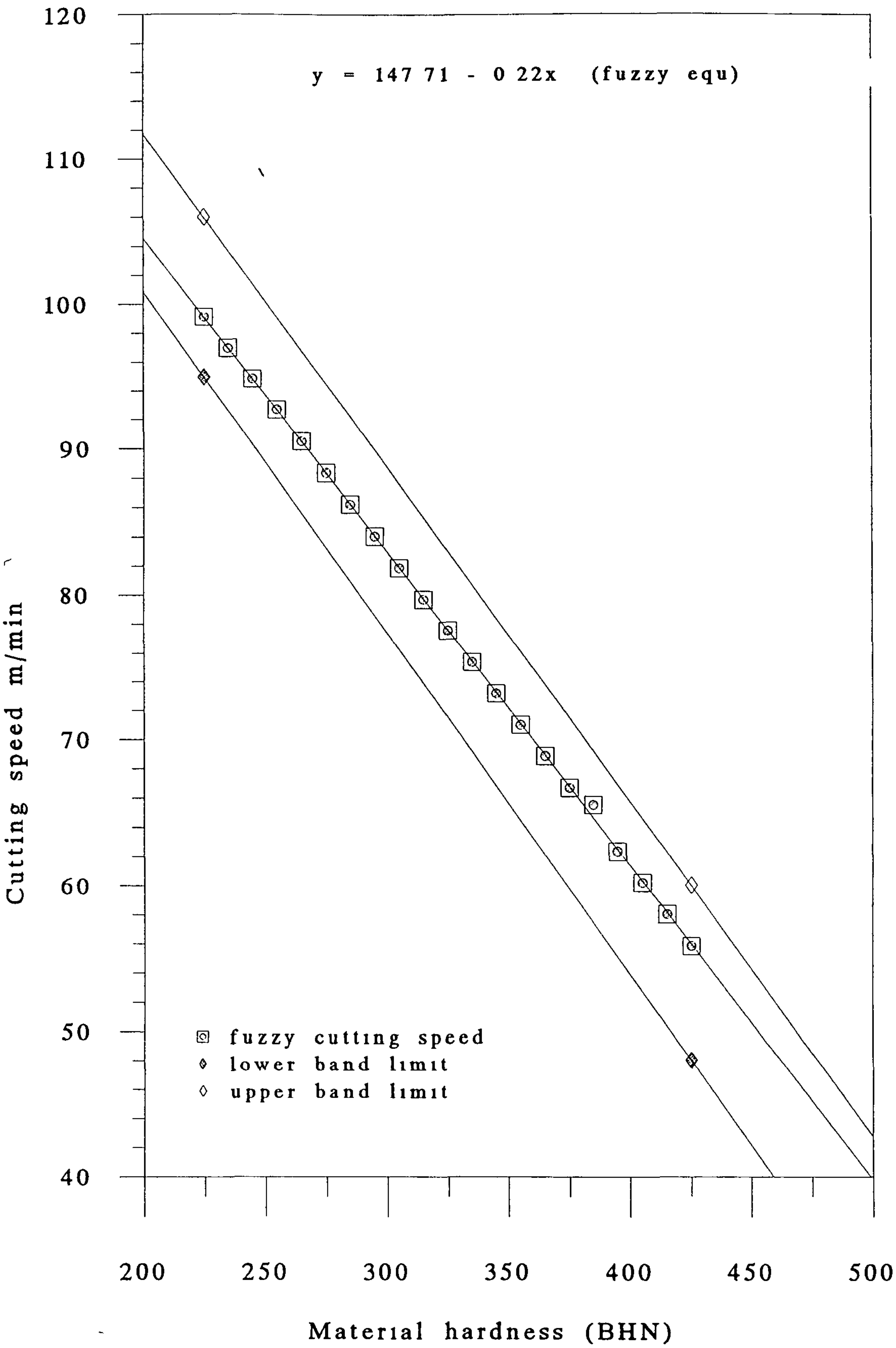


Fıg 5.14 Fuzzy cuttıng speed for Free machınıng carbon wrought steel at d o c 8 mm using Carbide uncoated brazed tool (model-1)

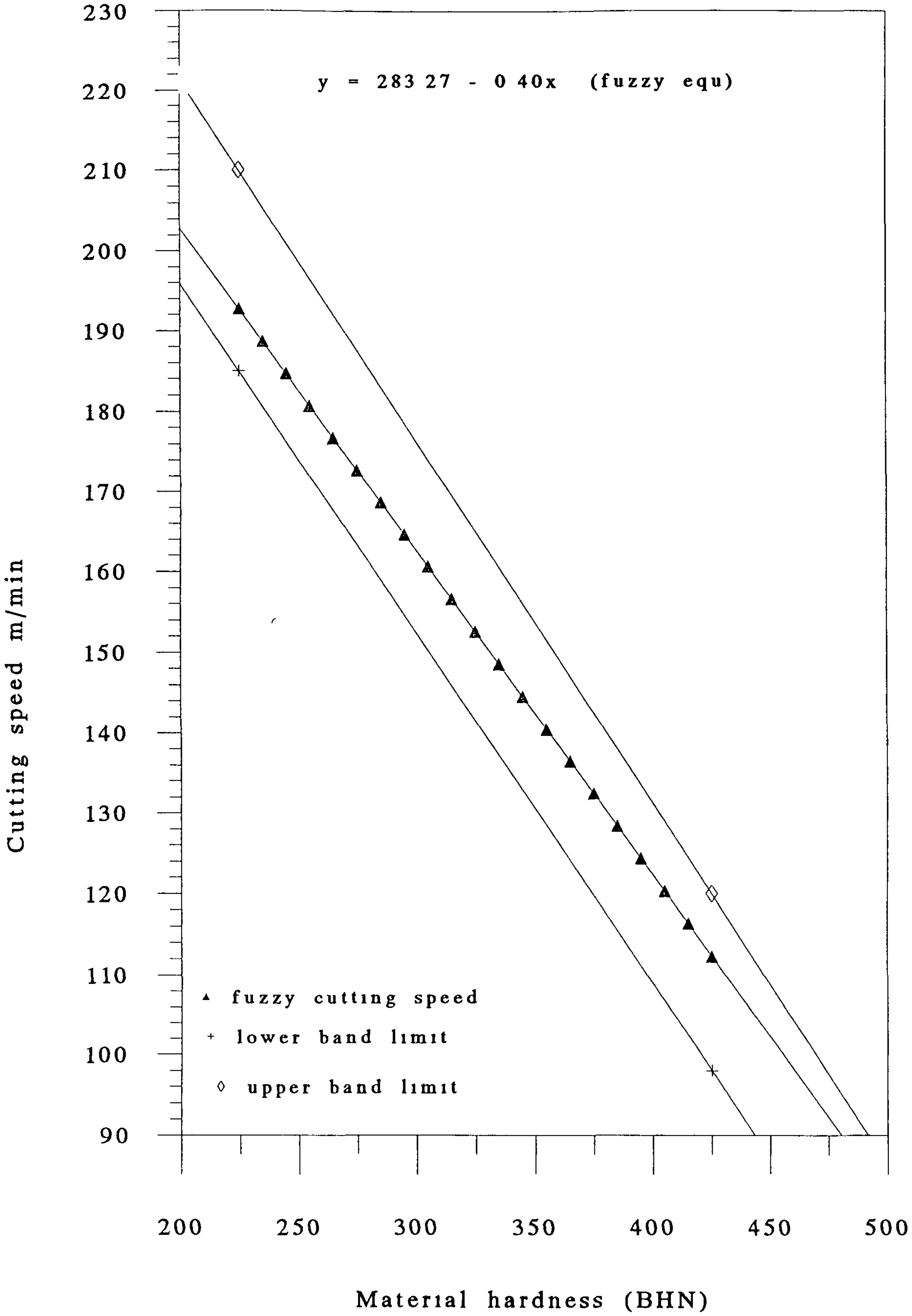


Fig 5.15 Fuzzy cutting speed for Free machinıng carbon wrought steel at d o c 1 mm usıng Carbıde uncoated ındexable tool (model-1)

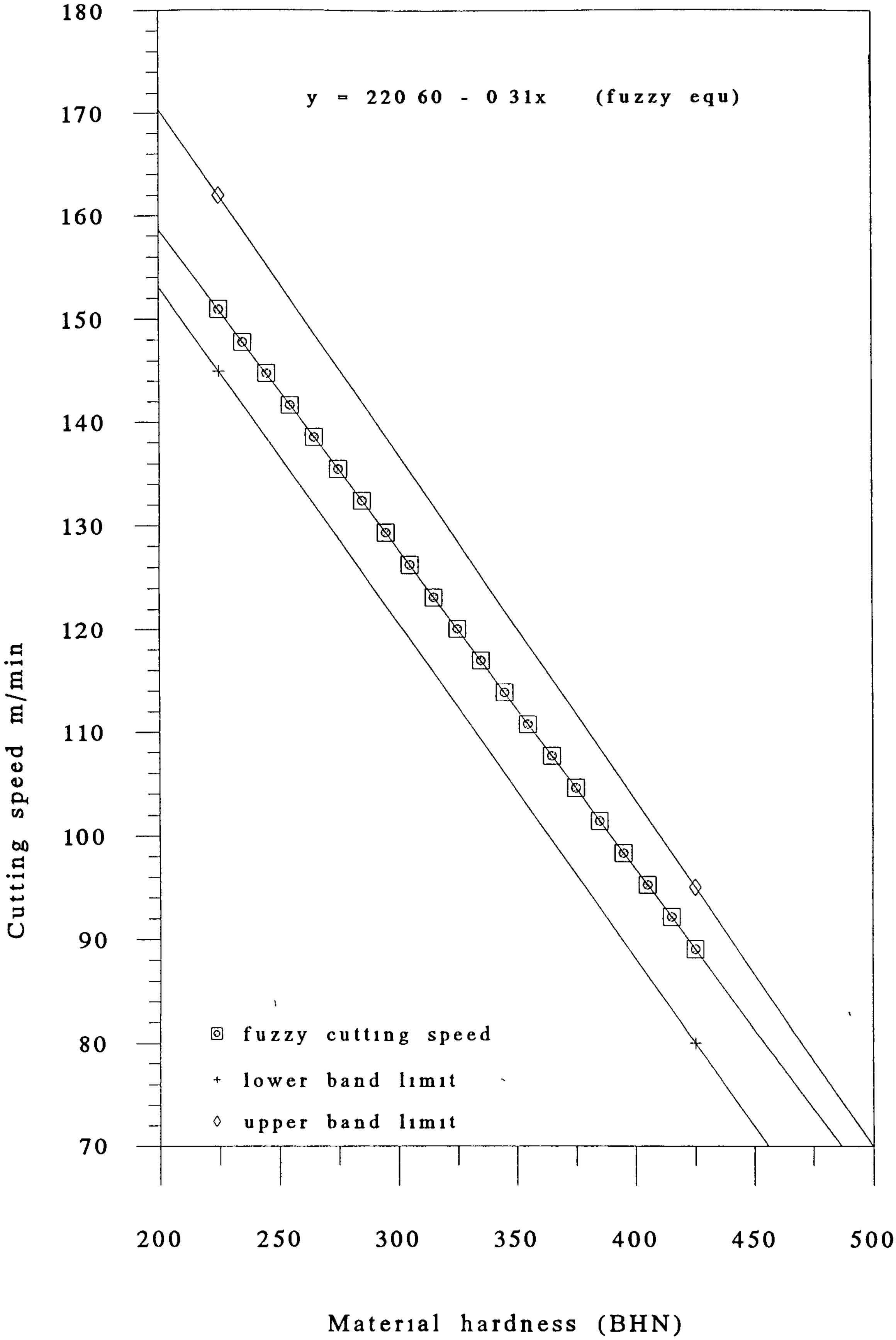


Fig 5.16 Fuzzy cutting speed for Free machining carbon wrought steel at d.o c 4 mm using Carbide uncoated indexable tool (model-1)

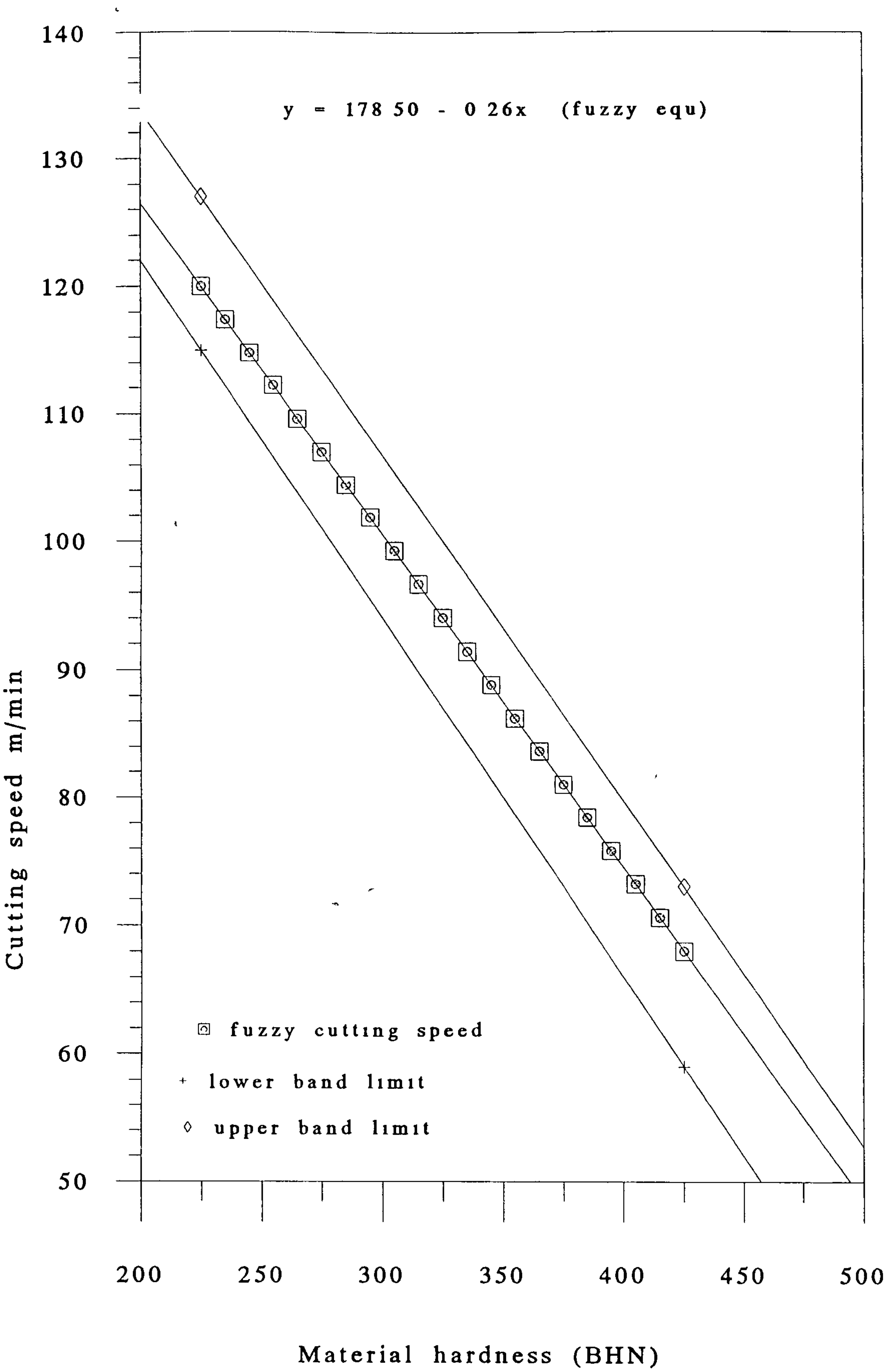


Fig 5.17 Fuzzy cutting speed for Free machining carbon wrought steel at d.o c 8 mm using Carbide uncoated indexable tool (model-1)

From Figures 5 6 to 5 17 it can be seen that the fuzzy cutting speeds obtained by applying the Fuzzy Model one are fitted nicely at the middle of the experimental data band

Table 5 13 shows the actual data for medium carbon leaded steel that have been used for calculations

Table 5.13 Machining Data for Medium Carbon Leaded Steel

Speed Range m/min	Depth of Cut	Tool Name
20-55	1mm	High Speed Steel Tool (H S S T)
17-43	4 mm	"
11-34	8mm	"
160-310	1mm	Carbide Tool - Coated (C T C)
105-205	4mm	"
84-160	8mm	"
87-170	1mm	Carbide Tool-Uncoated Brazed (C T U I)
67-130	4mm	"
52-100	8mm	"
115-220	1mm	Carbide Tool Uncoated Indexable (C T U I)
85-170	4mm	"
69-130	8mm	"

The results of the calculations obtained for Medium carbon leaded steel at three different depths of cut 1mm, 4mm and 8mm and using four different types of cutting tools are shown in Table 5 14, Table 5 15 and Table 5 16 respectively

Table 5.14 - Fuzzy Cutting Speed for

Medium Carbon Leaded Steel

(D.O.C. = 1 mm)

(BHN)	H.S.S.T	C.T.C.	C.T.U.B.	C.T.U.I.
125	57 00	318 57	174 14	225.99
140	55 05	310 21	170 11	220 14
155	53 10	301 85	165 49	214 29
170	51 15	293 50	160 87	208 44
185	49 20	285 14	156 24	202 59
200	47 25	276 78	151 62	196 75
215	45 30	268.42	146 99	190 90
230	43 35	260 07	142 37	185 05
245	41 40	251 71	137 74	179 20
260	39 45	243 35	133 12	173 35
275	37 50	235 00	128 50	167 50
290	35 55	226 64	123 87	161 65
305	33 60	218 28	119 25	155 80
320	31 65	209 92	114 62	149 95
335	29 70	201 57	110 00	144 10
350	27 75	193 21	105 37	138 25
365	25 79	184 85	100 75	132 40
380	23 84	176 50	96 12	126 55
395	21.89	168 14	91 50	120 70
410	19 94	159 78	86 88	114 85
425	17 99	151 42	82 25	109 00

Where D O C = Depth of cut
BHN = Material hardness

Tool Materials
H S S T = High speed steel tool
C T C = Carbide tool-coated
C.T.U.B = Carbide tool-uncoated brazed
C T U I = Carbide tool-uncoated indexable

Table 5.15 Fuzzy Cutting Speed for

Medium Carbon Leaded Steel

(D.O.C. = 4mm)

(BHN)	H.S.S.T	C.T.C.	C.T.U.B.	C.T.U.I.
125	44.48	210.71	133.60	174.85
140	43.03	205.14	130.09	170.12
155	41.58	199.57	126.58	165.38
170	40.13	194.00	123.07	160.64
185	38.69	188.42	119.56	155.91
200	37.24	182.85	116.05	151.17
215	35.79	177.28	112.54	146.44
230	34.34	171.71	109.03	141.70
245	32.89	166.14	105.52	136.97
260	31.44	160.57	102.01	132.23
275	30.00	155.00	98.50	127.50
290	28.55	149.42	94.99	122.76
305	27.10	143.85	91.48	118.02
320	25.65	138.28	87.97	113.29
335	24.20	132.71	84.46	108.55
350	22.75	127.14	80.95	103.82
365	21.30	121.57	77.44	99.08
380	19.86	116.00	73.93	94.35
395	18.41	110.42	70.42	89.61
410	16.96	104.85	66.91	84.87
425	15.51	99.28	63.40	80.14

Where D.O.C. = Depth of cut
BHN = Material hardness

Tool Materials
H.S.S.T. = High speed steel tool
C.T.C. = Carbide tool-coated
C.T.U.B.= Carbide tool-uncoated brazed
C.T.U.I. = Carbide tool-uncoated indexable

Table 5.16 Fuzzy Cutting Speeds for

Medium Carbon Leaded Steel

(D.O.C. = 8mm)

(BHN)	H.S.S.T	C.T.C.	C.T.U.B.	C.T.U.I.
125	35 31	164 34	102 74	133 48
140	34 03	160 10	100 06	130 08
155	32 75	155 87	97 39	126 68
170	31 47	151 64	94 72	123 29
185	30 18	147 40	92 04	119 89
200	28 90	143 17	89 37	116 49
215	27 62	138 93	86 69	113 09
230	26 34	134 70	84 02	109 69
245	25 06	130 46	81 34	106 29
260	23 78	126 23	78 67	102 89
275	22 50	122 00	76 00	99 50
290	21 21	117 76	73 32	96 10
305	19 93	113 53	70 65	92 70
320	18 65	109 29	67 97	89 30
335	17 37	105 06	65 30	85 90
350	16 09	100 82	62 62	82 50
365	14 81	96 59	59 95	79 10
380	13 53	92 35	57 28	75 70
395	12 24	88 12	54 60	72 31
410	10 96	83 89	51 93	68 91
425	9 68	79 65	49 25	65 51

Where D O C = Depth of cut
BHN = Matenal hardness
Tool Matenals
H S S T = Hıgh speed steel tool
C T C = Carbıde tool-coated
C T U B = Carbıde tool-uncoated brazed
C T U I = Carbıde tool-uncoated ındexable

Usıng fuzzy model-1, the relatıonshıp between the cuttıng speed and hardness for Medıum Carbon Leaded Steel at three dıfferent depths of cut (1mm, 4mm and 8mm) and usıng four dıfferent cuttıng tools are establıshed and summarısed ın Table 5 17

Table 5.17 Equations for Medıum Carbon Leaded Steel

Tool Used	Equation	No.	DOC
High Speed Steel Tool	Y = 73 26 - 0 13x	(5-27)	D O C = 1mm
	Y = 56 55 - 0 10x	(5-28)	D O C = 4mm
	Y = 45 99 - 0 07x	(5-29)	D O C = 8mm
Carbide Tool-Coated	Y = 388 21 - 0 56x	(5-30)	D O C = 1mm
	Y = 257 14 - 0 37x	(5-31)	D O C = 4mm
	Y = 199 34 - 0 28x	(5-32)	D O C = 8mm
Carbide Tool-Uncoated Brazed	Y = 213 28 - 0 31x	(5-33)	D O C = 1mm
	Y = 162 85 - 0 23x	(5-34)	D O C = 4mm
	Y = 125 02 - 0 18x	(5-35)	D O C = 8mm
Carbide Tool-Uncoated Indexable	Y = 274 74 - 0 39x	(5-36)	D O C = 1mm
	Y = 214 32 - 0 32x	(5-37)	D O C = 4mm
	Y = 161 80 - 0 23x	(5-38)	D O C = 8mm

Where D O C = Depth of Cut

Fıg 5 18 to 5 20 show the graphıcal presentatıon of the fuzzy cuttıng speeds obtaıned for Medıum Carbon Leaded Steel at three dıfferent depths of cut 1mm, 4mm and 8mm and usıng a hıgh speed steel cuttıng tool From these figures ıt can be seen that the fuzzy cuttıng speeds obtaıned for Medıum Carbon Leaded Steel usıng fuzzy model-1, generally lıe wıthın the band of the experımental data However, the cuttıng speeds accordıng to fuzzy logıc presentatıon lıe closer to the lower lımıt of the experımental band for lower hardness values and the fuzzy cuttıng speed for hıgher hardness values he closer to the upper lımıt of the experımental band

Fıg 5 21 to fig 5 23 represent the fuzzy cuttıng speeds obtaıned for medıum carbon leaded steel at three depths of cut 1mm, 4mm and 8mm and usıng a carbıde tool-coated Each of these figures also show the lower and upper lımıts of the cuttıng speed band obtained by plotting the data from the machining data hand book [99] . From the figures it can be seen that the cutting speed values obtained from the fuzzy model 1 generally lie towards the middle of the band of the machining data.

The fuzzy cutting speeds presentation for 1mm and 8 mm in Figs. 5.21 and 5.23 fall almost at the middle of the experimental data band, whereas the fuzzy cutting speed for 4 mm in Fig. 5.22 has slight tendency to go closer to the upper band of the cutting speed data for higher hardness values.

Figs 5.24 to 5.26 show the graphical presentation of the fuzzy cutting speeds obtained for medium carbon leaded steel at three depths of cut 1mm, 4mm and 8mm and using a carbide tool-uncoated brazed. Each of these figures also presents the lower and upper limits of the cutting speed band obtained by plotting the data from reference [99]. From these figures it can be seen that the fuzzy cutting speeds fall within the lower and the upper limit of the data band.

The fuzzy cutting speeds for depth of cut of 1 mm and 8 mm in Figs. 5.24 and 5.26 respectively lie at the middle of the experimental lower and upper band limits of the cutting speed. For depth of cut of 4 mm in Fig. 5.23 the cutting speed values for higher hardness values have little inclination towards the upper band limit whereas the cutting speed values for lower hardness values have tendency for staying close to the lower band limit of the experimental data.

Figs 5.27 to 5.29 represent the fuzzy cutting speeds obtained for medium carbon leaded steel at three depths of cut 1mm, 4mm, 8mm and using a carbide tool-uncoated indexable. Each of these figures also shows the lower and upper limits of the experimental data obtained by plotting from reference [99]. From the graphical representation it shows that the fuzzy cutting speeds obtained from the fuzzy model 1 lie reasonably within the lower and upper limit of the experimental data band. But the fuzzy cutting speed for lower hardness value at depth of cut of 1 mm in Fig. 5.27 fall close to the lower limit and the fuzzy cutting speed for higher hardness value fall close to the upper limit of the experimental data band.

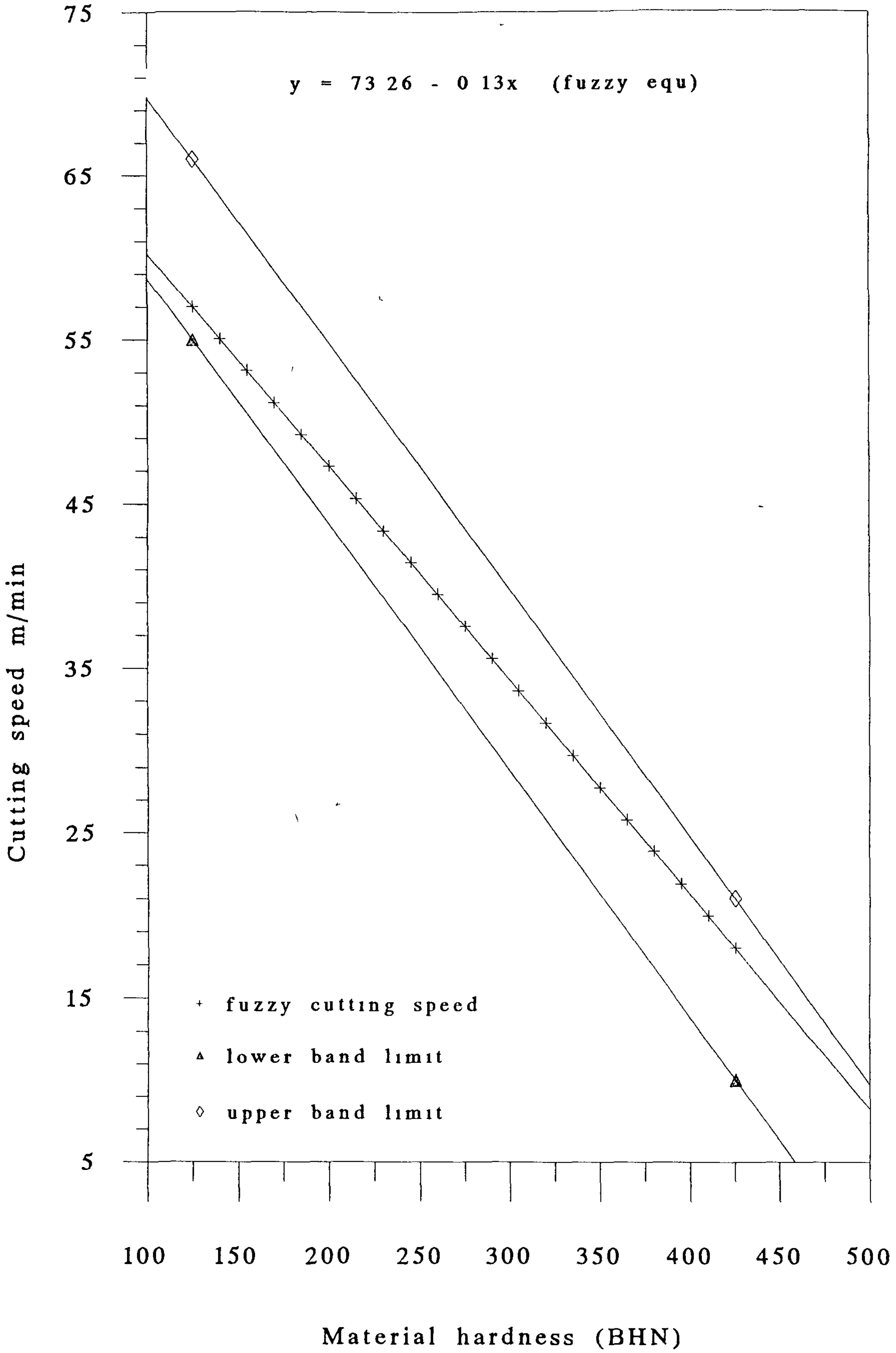


Fig 5.18 Fuzzy cutting speed for Medium carbon leaded steel at d o c 1 mm using High speed steel tool (model-1)

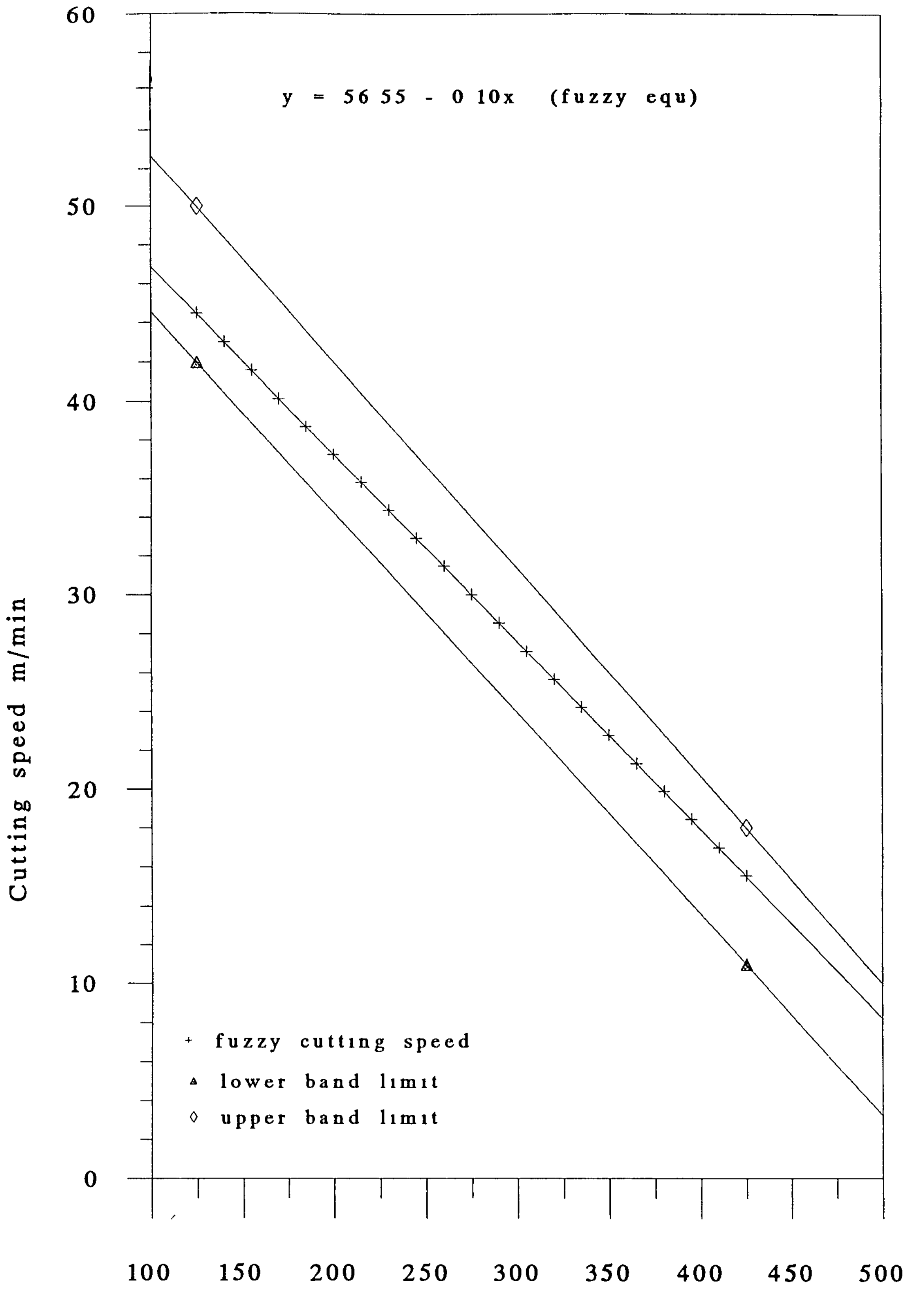


Fıg 5.19 Fuzzy cutting speed for Medıum carbon leaded steel at d.o.c 4 mm using Hıgh speed steel tool (model-1)

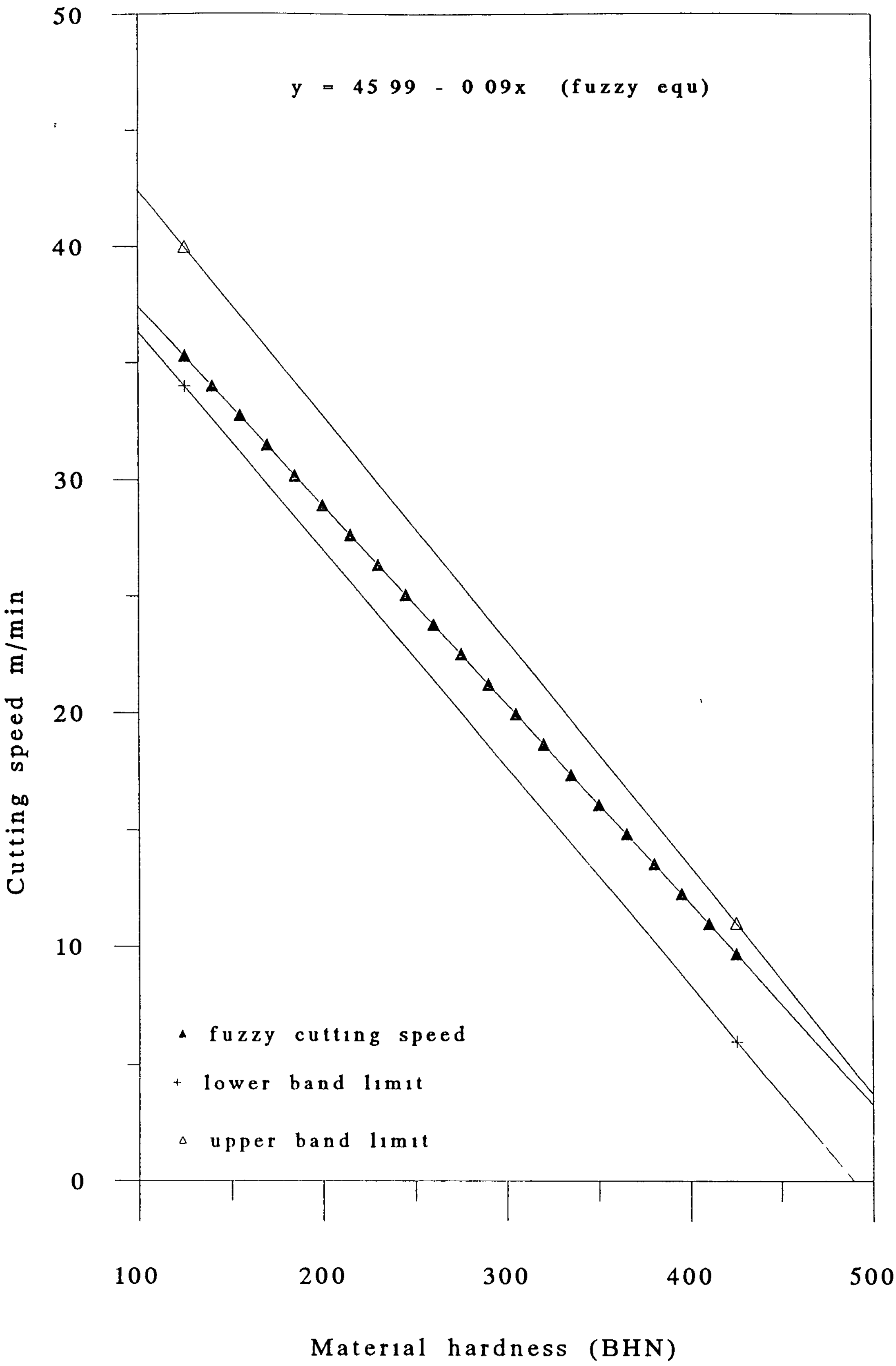


Fig 5.20 Fuzzy cuttıng speed for Medıum carbon leaded steel at d.o.c. 8 mm using Hıgh speed steel tool (model-1)

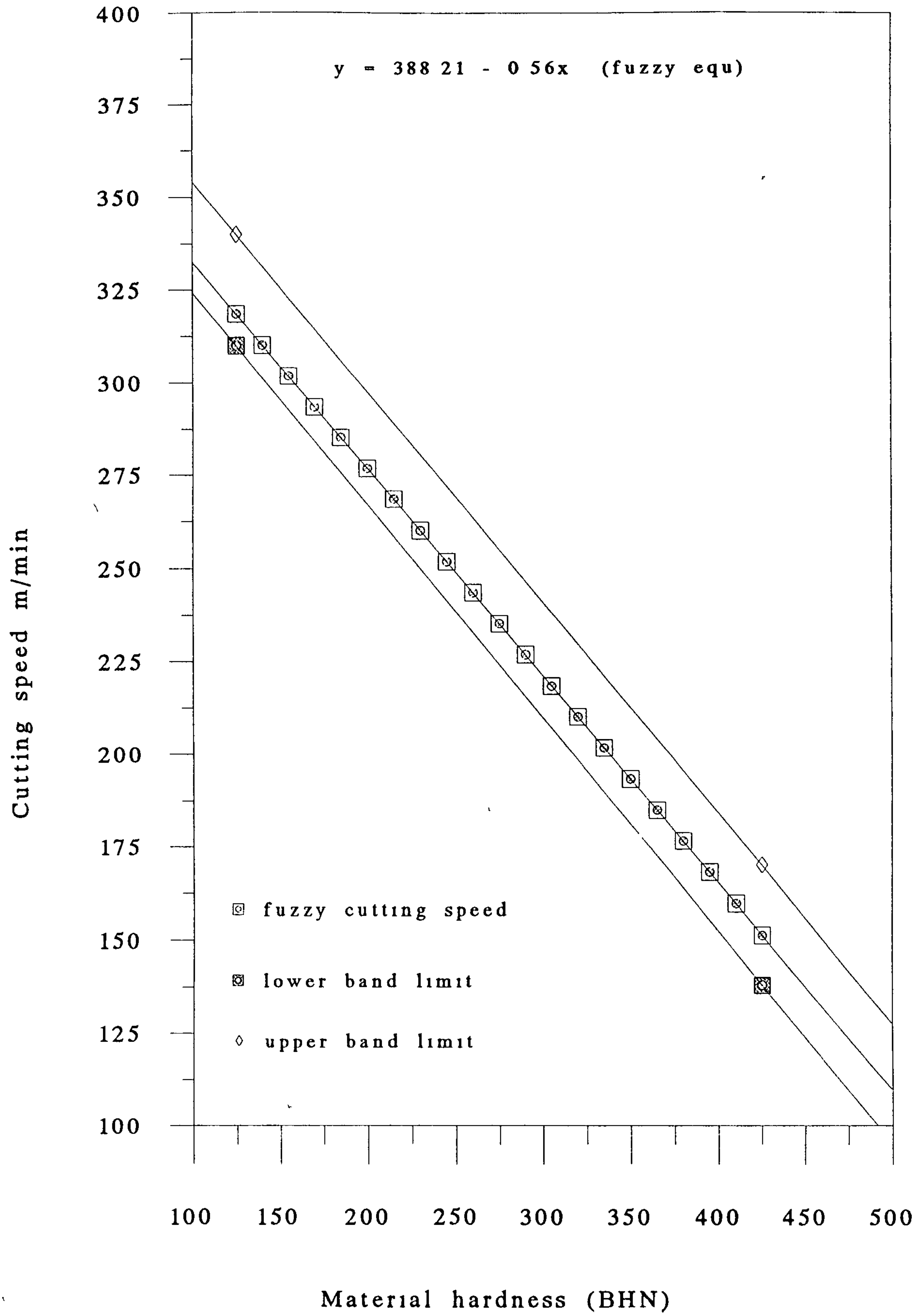


Fig 5.21 Fuzzy cutting speed for Medium carbon leaded steel at d.o.c 1 mm using Carbide coated tool (model-1)

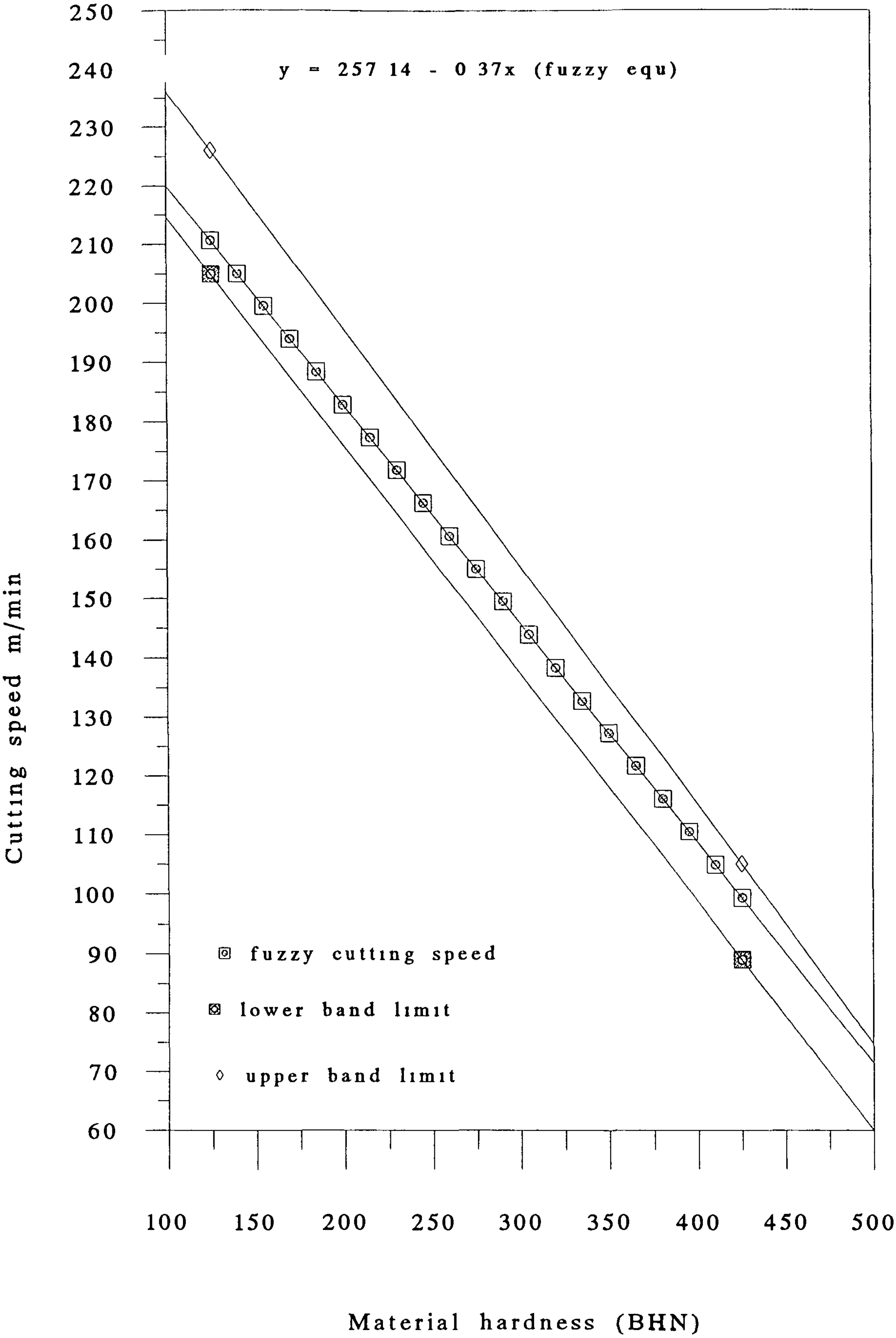


Fig 5.22 Fuzzy cutting speed for Medium carbon leaded steel at d o c 4 mm using Carbide coated tool (model-1)

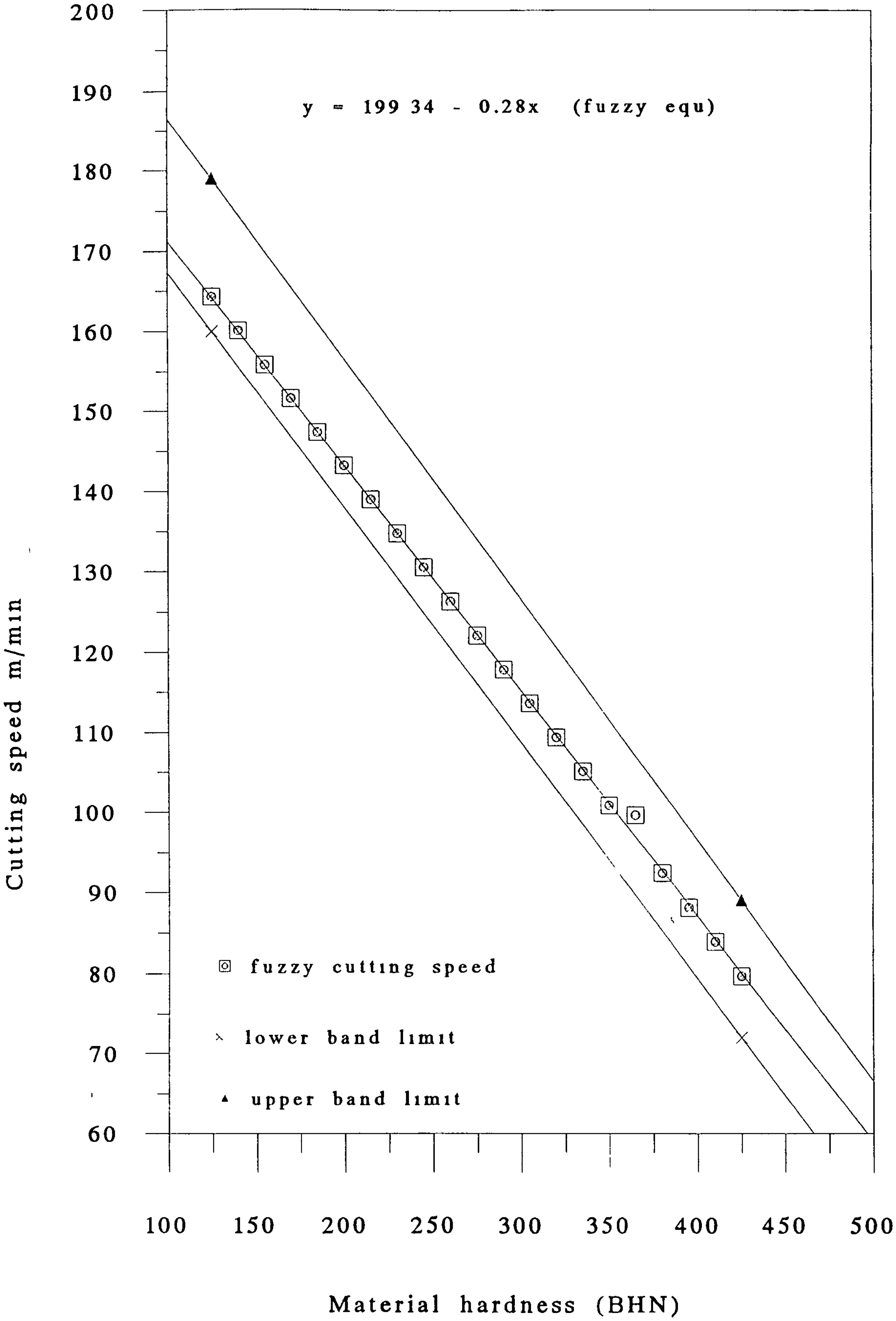


Fig 5 23 Fuzzy cutting speed for Medıum carbon leaded steel at d o c 8 mm using Carbıde coated tool (model-1)

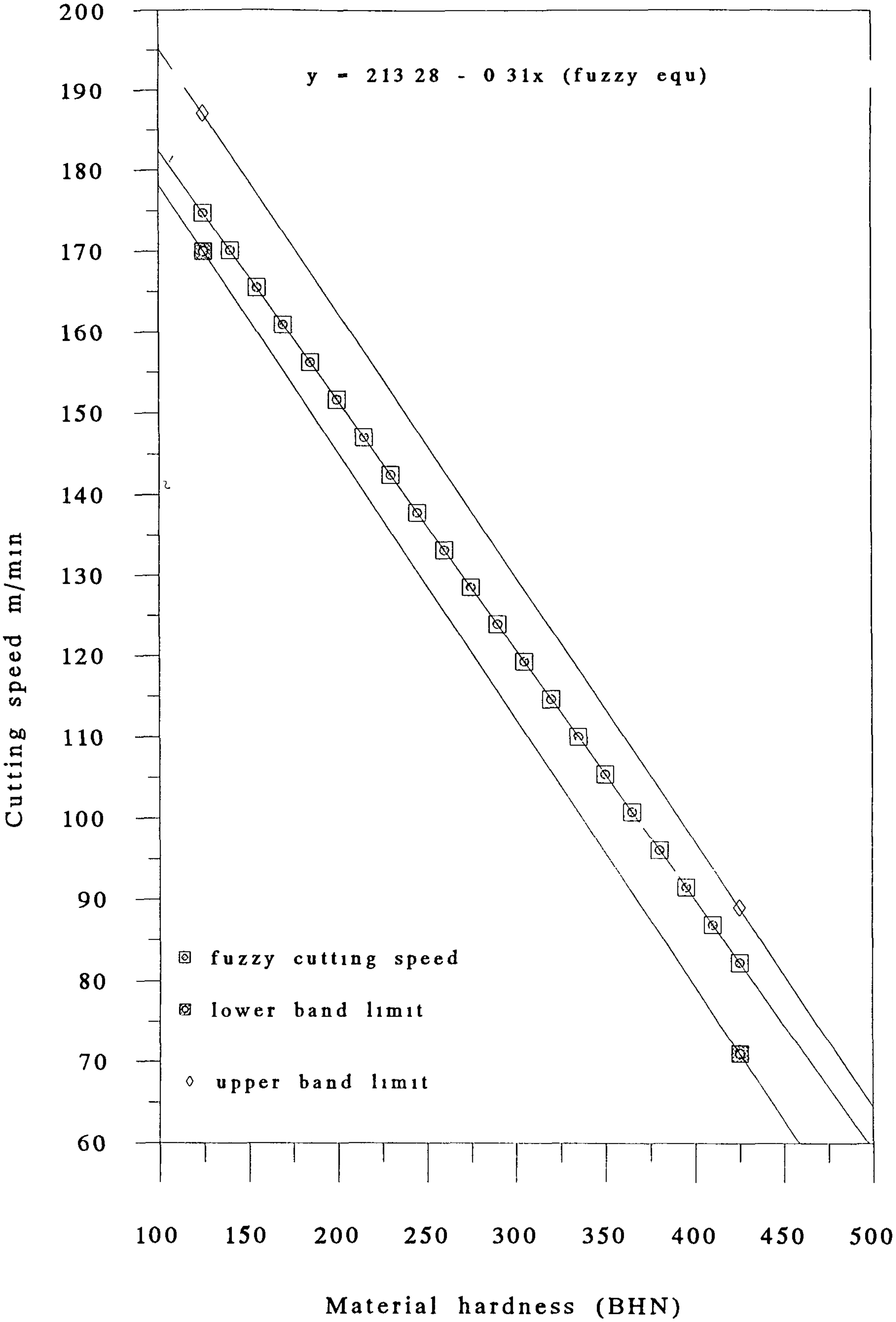


Fig 5.24 Fuzzy cutting speed for Medium carbon leaded steel at d o c 1 mm using Carbide uncoated brazed tool (model-1)

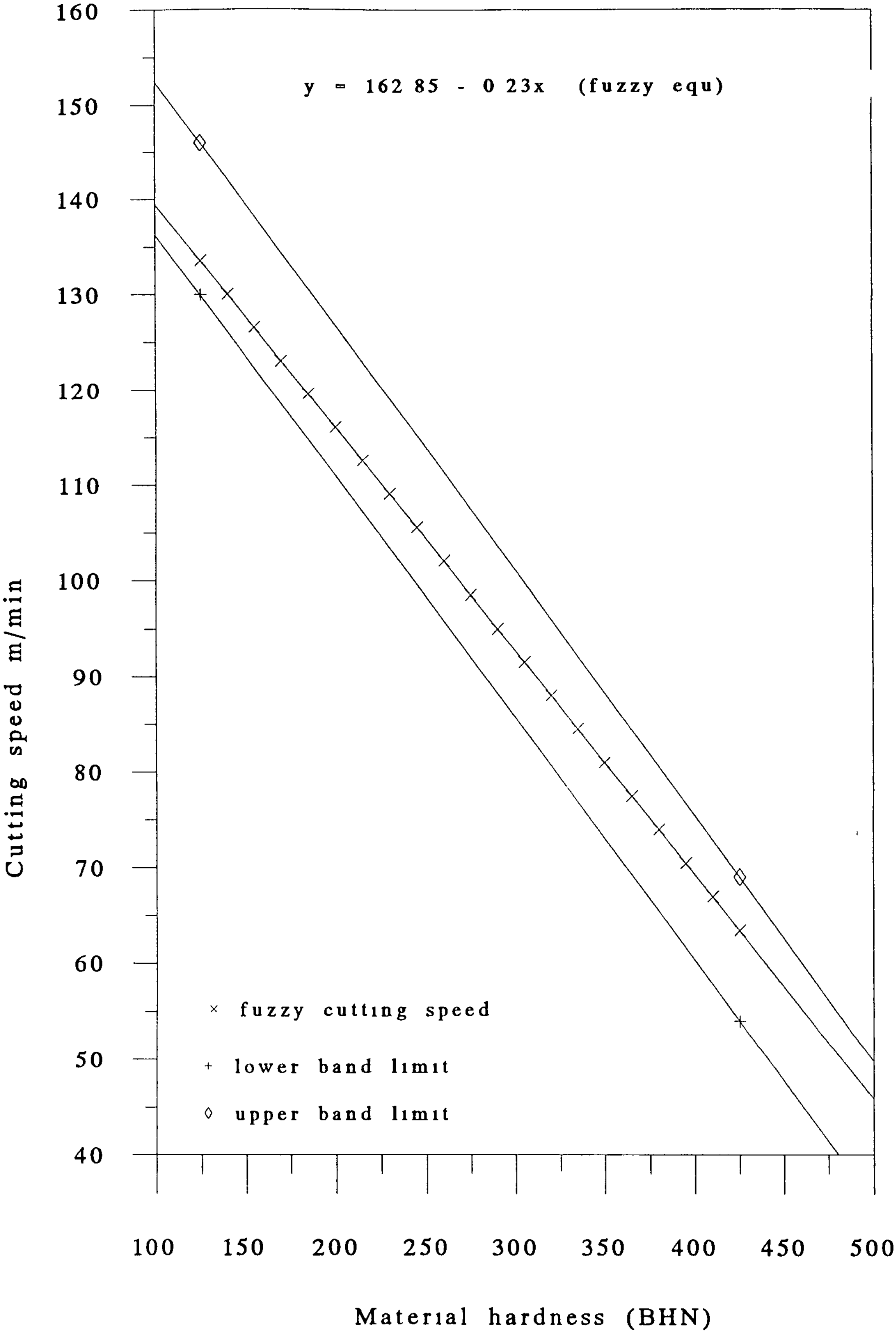


Fıg 5.25 Fuzzy cutting speed for Medıum carbon leaded steel at d o.c 4 mm using Carbıde uncoated brazed tool (model-1)

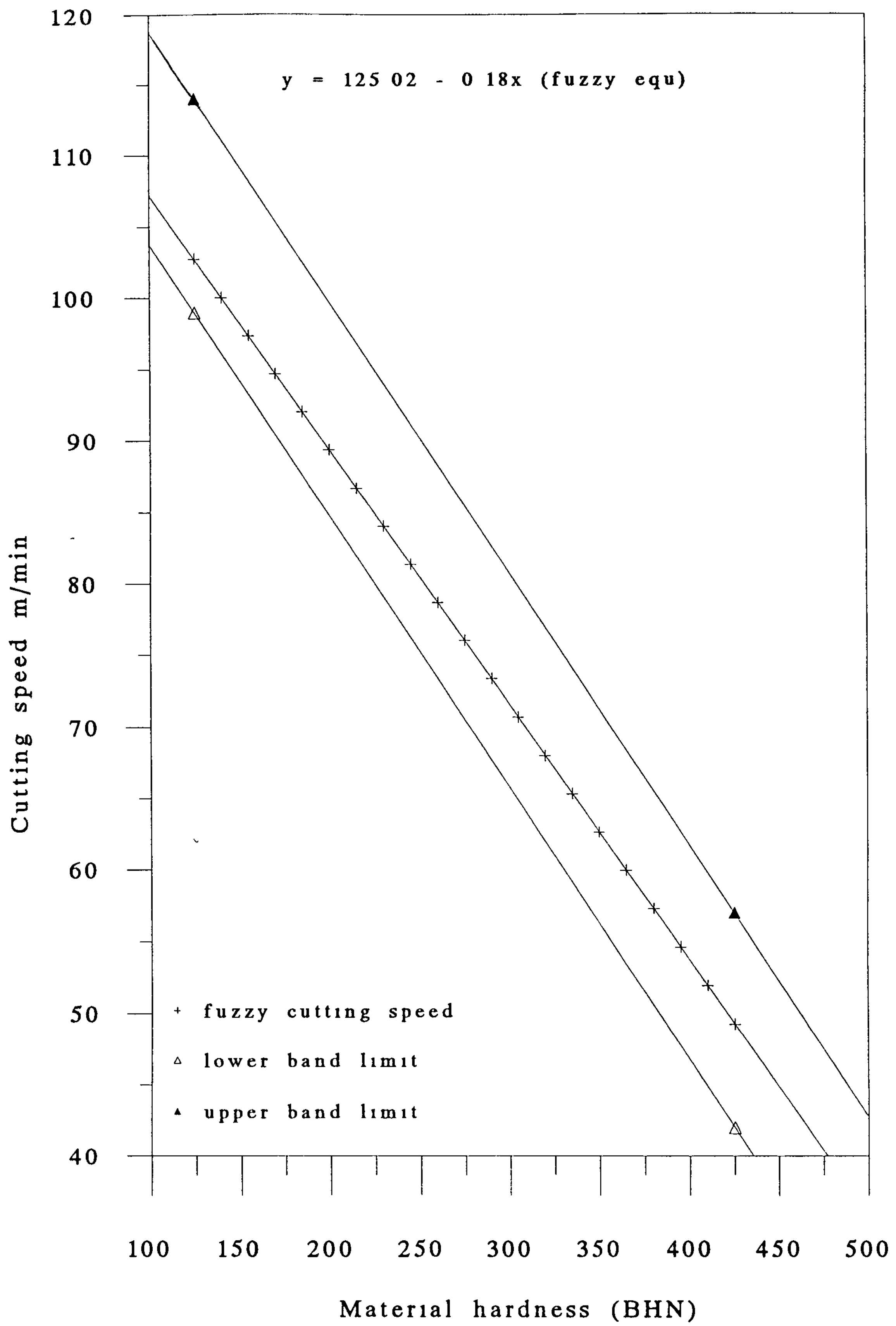


Fıg 5.26 Fuzzy cuttıng speed for Medium carbon leaded steel at d o c 8 mm using Carbide tool-uncoated brazed (model-1)

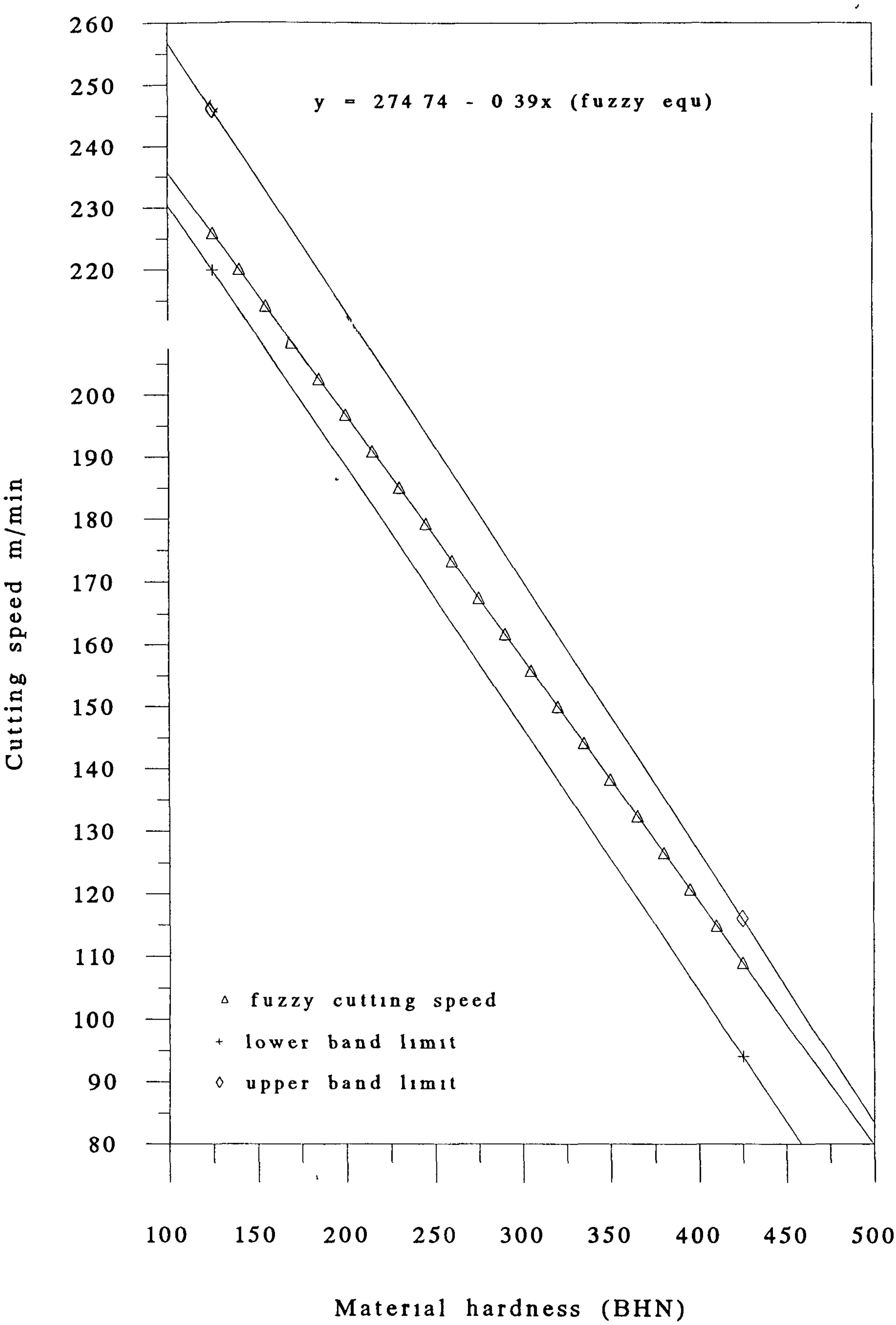


Fig 5.27 Fuzzy cutting speed for Medium carbon leaded steel at d o c 1 mm using Carbide tool-uncoated indexable (model-1)

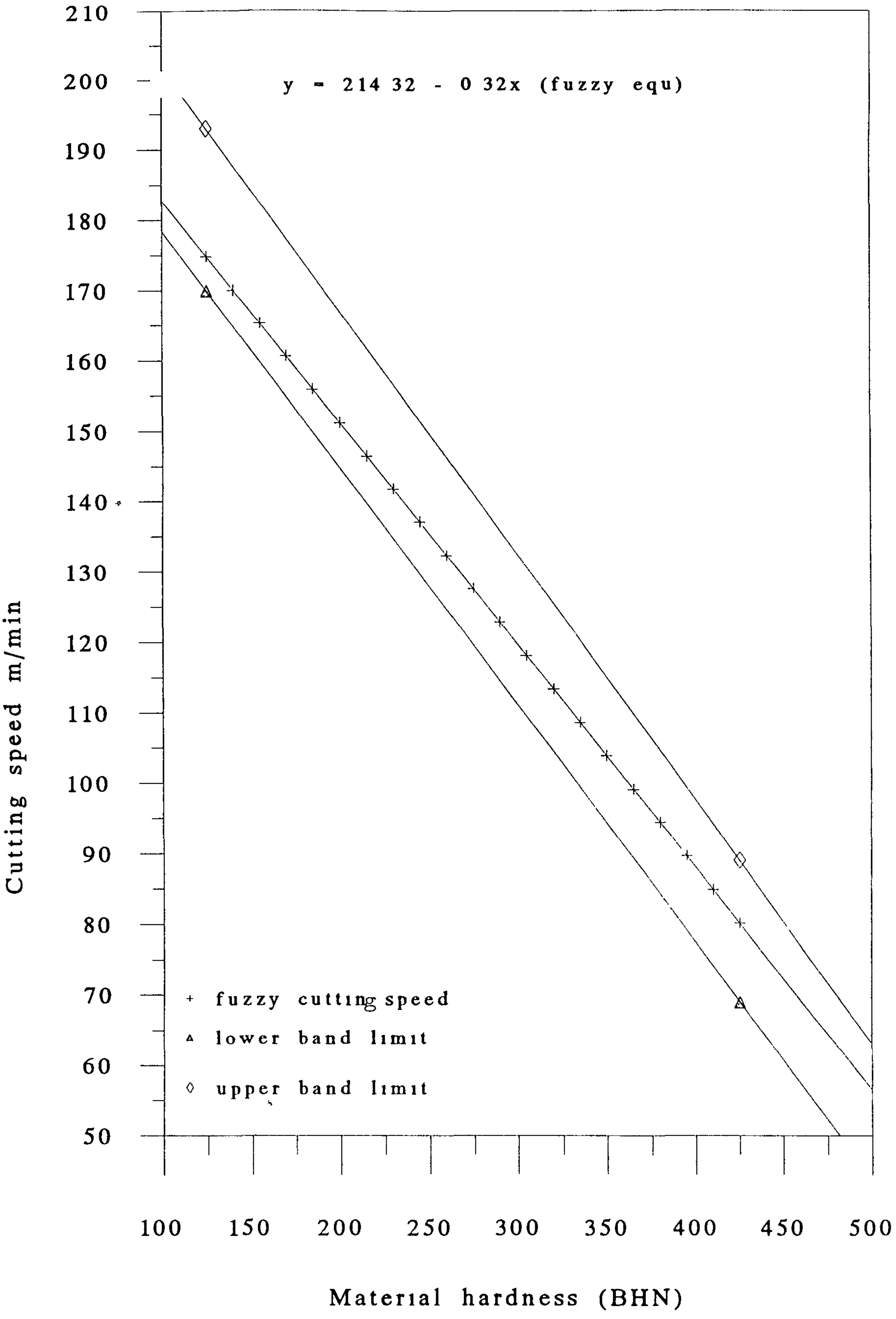


Fig 5.28 Fuzzy cutting speed for Medium carbon leaded steel at d o c 4 mm using Carbide tool-uncoated indexable (model-1)

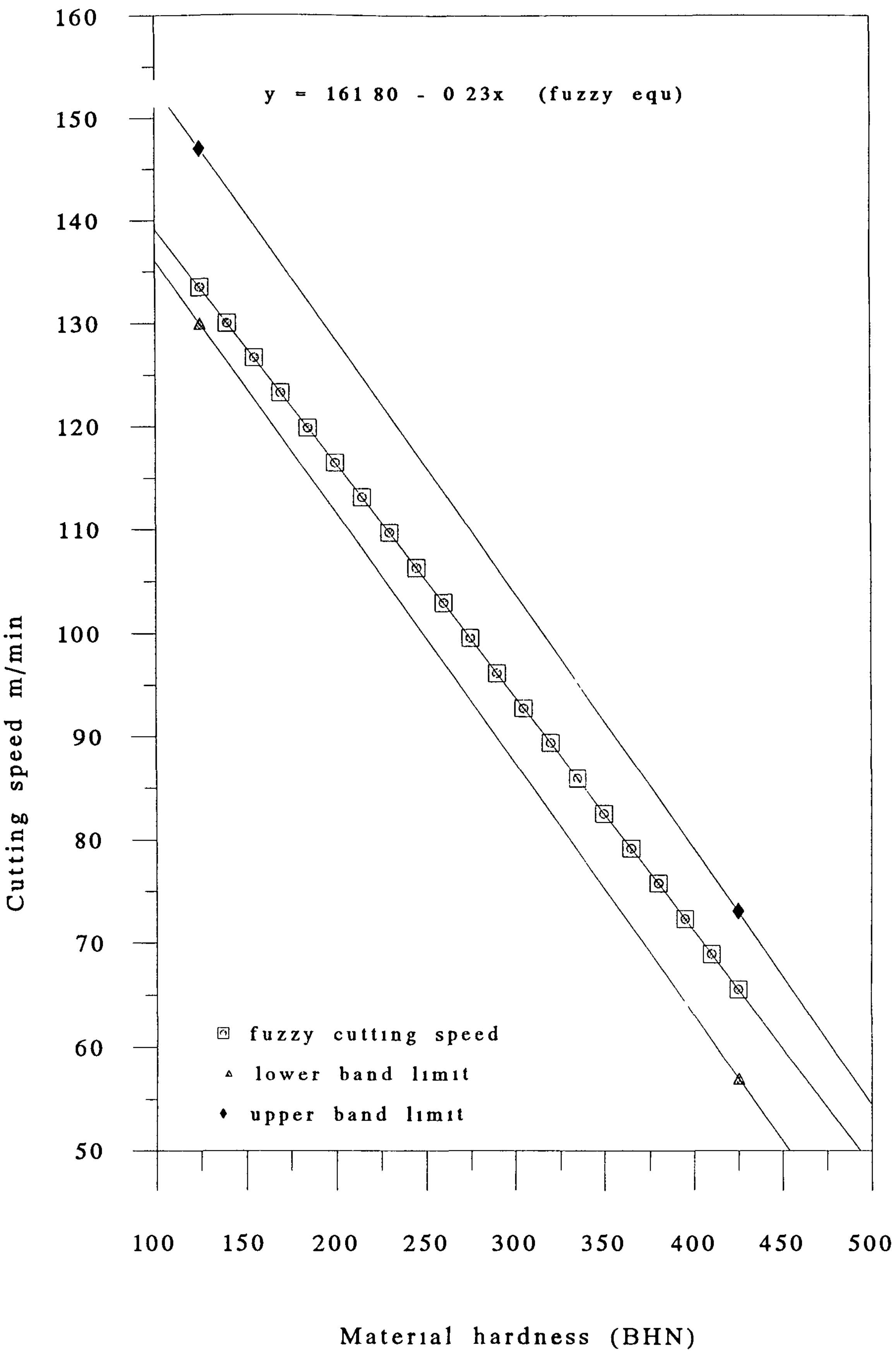


Fig 5.29 Fuzzy cutting speed for Medium carbon leaded steel at d o.c 8 mm using Carbide tool-uncoated indexable (model-1)

In Figs. 5.28 and 5.29 the fuzzy cutting speed for lower hardness at depth of cut of 4 mm and 8 mm lie closer to the lower band limit whereas the fuzzy cutting speed for higher hardness value lie within the middle of the bands showing very good fuzzy presentation of experimental data.

5.7 Development of Fuzzy (Model-2)

The similar triangular shapes have been employed to describe the fuzzy sets for fuzzy input/output variables. In this model the fuzzy sets overlapped with the adjacent set at 33% level. Seven fuzzy sets for input fuzzy variable (HARDNESS) are listed below and shown in Fig 5.30.

Input Fuzzy Variable | **Fuzzy Sets**

HARDNESS
- VS .... (very soft)
- SO .... (soft)
- MS ....(medium soft)
- ME .... (medium)
- MH ....(medium hard)
- HA ....(hard)
- VH ....(very hard)

Fig 5.30 Fuzzy Sets for Input Variable (HARDNESS)

Membership functions for material hardness is shown in Fig. 5.31.

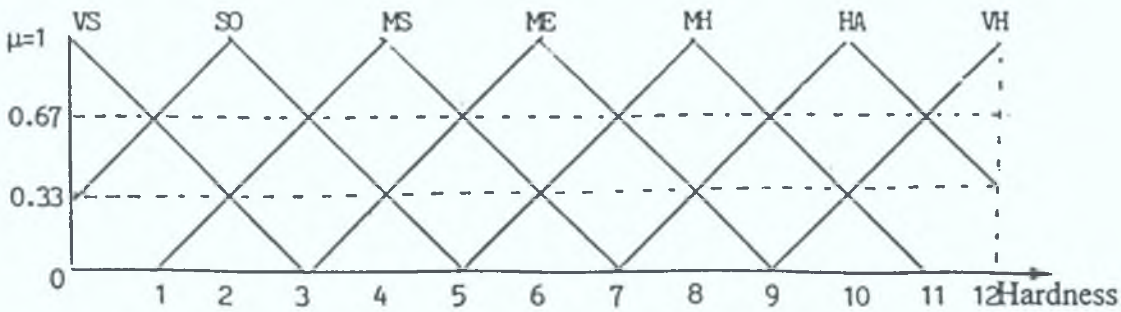


Fig 5.31 Metal Hardness Membership (Model-2)

Seven fuzzy sets for output fuzzy variable (SPEED) are listed below and shown in Fig 5 32.

Output Fuzzy Variable **Fuzzy Sets**

SPEED
- VSLOW. (very slow)
- SLOW ..... .(slow)
- MSLOW ... .(medium slow)
- MEDI .... (medium)
- MHIGH ... (medium high)
- HIGH .... ..(high)
- VHIGH ..... .(very high)

Fig 5.32 Fuzzy Sets for Output Variable (SPEED)

Membership functions for cutting speed is shown in Fig 5 33.

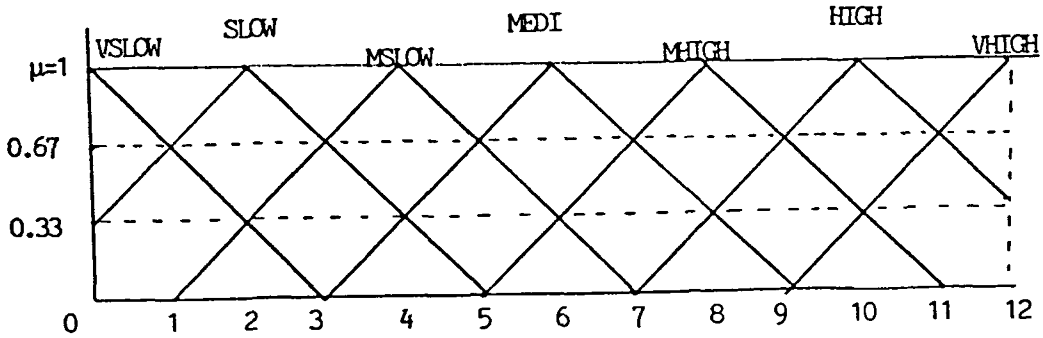


Fig 5.33 Cutting Speed Membership (Model-2)

The universe of input (HARDNESS) and output (SPEED) have been partitioned into (0-12) units as shown in Fig 5 31 and Fig 5 33 From Fig 5 31 and 5 33. Different membership values are assigned to each fuzzy sets and the descretized universe of fuzzy variables (HARDNESS, and SPEED) have been developed as shown in Table 5 18 and Table 5.19 respectively

Table 5.18 Descretized Universe of Materıal Hardness

Fuzzy Terms	0	1	2	3	4	5	6	7	8	9	10	11	12
VS	1	67	33	0	0	0	0	0	0	0	0	0	0
SO	33	67	1	67	0	0	0	0	0	0	0	0	0
MS	0	0	33	67	1	67	33	0	0	0	0	0	0
ME	0	0	0	0	33	67	1	67	33	0	0	0	0
MH	0	0	0	0	0	0	33	67	1	67	33	0	0
HA	0	0	0	0	0	0	0	0	33	67	1	67	33
VH	0	0	0	0	0	0	0	0	0	0	33	67	1

Table 5.19 Discretized Universe of Cutting Speed

	0	1	2	3	4	5	6	7	8	9	10	11	12
VSLOW	1	67	33	0	0	0	0	0	0	0	0	0	0
SLOW	33	67	1	67	33	0	0	0	0	0	0	0	0
MSLOW	0	0	33	67	1	67	33	0	0	0	0	0	0
MEDI	0	0	0	0	33	67	1	67	33	0	0	0	0
MEDH	0	0	0	0	0	0	33	67	1	67	33	0	0
HIGH	0	0	0	0	0	0	0	0	33	67	1	67	33
VHIGH	0	0	0	0	0	0	0	0	0	0	33	67	1

Rules for Model-2

Seven rules are employed for the fuzzy controller ın model-2 and they are lısted ın Table 5 20

Table 5.20 Fuzzy Rules for Model-2

Rule 1 IF materıal HARDNESS ıs VS THEN SPEED ıs VHIGH

Rule 2 IF materıal HARDNESS ıs SO THEN SPEED ıs HIGH

Rule 3 IF materıal HARDNESS ıs MS THEN SPEED ıs MEDH

Rule 4 IF materıal HARDNESS ıs ME THEN SPEED IS MEDI

Rule 5 IF materıal HARDNESS ıs MH THEN SPEED IS MSLOW

Rule 6 IF material HARDNESS is HA THEN SPEED IS SLOW

Rule 7 IF material HARDNESS is VH THEN SPEED IS VSLOW

Fuzzy Relation.

Fuzzy relation between input and output fuzzy sets has been worked out exactly the same way as for model-1 The total combination of the seven relations using 'OR' operator is the maximum of the membership Thus the fuzzy algorithm

IF material hardness = VS, THEN speed = VHIGH OR
IF material hardness = SO, THEN speed = HIGH OR
IF material hardness = MS, THEN speed = MHIGH OR
IF material hardness = ME, THEN speed = MEDI OR
IF material hardness = MH, THEN speed = MSLOW OR
IF material hardness = HA, THEN speed = SLOW OR
IF material hardness = VH, THEN speed = VSLOW

can be represented in the relation R which has a membership function of

$$\mu_R = \text{Max}\ \{\mu_{R1}, \mu_{R2}, \mu_{R3}, \mu_{R4}, \mu_{R5}, \mu_{R6}, \mu_{R7}\}$$

This μ_R is represented in Table 5 21

Table 5.21 Membership Function for Seven Rules

Model-2

Universe of Cutting Speed

Universe of Metal Hardness

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
0	0	0	0	0	0	0	0	0	33	33	33	67	1
1	0	0	0	0	0	0	0	0	33	67	67	67	67
2	0	0	0	0	0	0	33	33	33	67	1	67	33
3	0	0	0	0	0	0	33	67	67	67	67	67	33
4	0	0	0	0	33	33	33	67	1	67	33	33	33
5	0	0	0	0	33	67	67	67	67	67	33	0	0
6	0	0	33	33	33	67	1	67	33	33	33	0	0
7	0	0	33	67	67	67	67	67	33	0	0	0	0
8	33	33	33	67	1	67	33	33	33	0	0	0	0
9	33	67	67	67	67	67	33	0	0	0	0	0	0
10	33	67	1	67	33	33	33	0	0	0	0	0	0
11	67	67	67	67	33	0	0	0	0	0	0	0	0
12	1	67	33	33	33	0	0	0	0	0	0	0	0

The defuzzified output which gives the average speed value for hardness universe (0-12) can be obtained by using the eg (3-24) in Chap 3 and shown in Table 5 22

Table 5.22 Average Speed for Hardness (0-12)

Hardness Universe Partitioning	Average Speed
0	10 63
1	10 22
2	9 37
3	9 00
4	8 00
5	7 00
6	6 00
7	5 00
8	4 00
9	3 00
10	2 63
11	1 77
12	1 37

5.8 Theoretical Results using Fuzzy (Model-2) and Discussions

The results of the calculations obtained for Medium Carbon Leaded Steel using Model-2, at three different depths of cut (1mm, 4mm and 8mm), using four different types of cutting tools are shown in Table 5.23, Table 5 24 and Table 5 25 respectively

The relationship between the cutting speed and material hardness for medium carbon leaded steel are established and summarised in Table 5 26

Table 5.23 Fuzzy Cutting Speed for

Medium Carbon Leaded Steel Model-2

(D.O.C. = 1mm)

(BHN)	H.S.S.T	C.T.C.	C.T.U.B.	C.T.U.I.
125	54 81	311 00	170 22	220 70
150	51 81	298 50	163 22	211 95
175	48 81	286 00	156 22	203 20
200	45 81	273 50	149 22	194 45
225	42 21	261 00	142 22	185 70
250	39 81	248 50	135 22	176 95
275	36 81	236 00	128 22	168 20
300	33 81	223 50	121 22	159 45
325	30 81	211.00	114 22	150.70
350	27 81	198 50	107 22	141.95
375	24 81	186 00	100 22	133 20
400	31 81	173 50	93 22	124 45
425	18 81	161 00	86 22	115 70

where BHN = Matenal Hardness
D O C = Depths of Cut

Tool Matenals
H S S T = Hıgh Speed Steel Tool
C T C = Carbıde Tool-Coated
C T U B = Carbıde Tool-Uncoated Brazed
C T U I = Carbıde Tool-Uncoated ındexable

Table 5.24 Fuzzy Cutting Speed for Medium Carbon

Leaded Steel (Model-2)

D.O.C. = 4 mm.

(BHN)	H.S.S.T	C.T.C.	C.T.U.B.	C.T.U.I.
125	42 75	204 83	130 42	169 73
150	40 50	196 33	125 17	162 48
175	38 25	187 83	119 92	155 23
200	36 00	179 33	114 67	147 98
225	33 30	170 83	109 42	140 73
250	31 50	162 33	104 17	133 48
275	29 25	153 83	98 92	126 23
300	27 00	145 33	93 67	118 98
325	24 75	136 83	88 42	111 78
350	22 50	128 33	83 17	104 48
375	20 25	119 83	77 92	97 23
400	18 00	111 33	72 67	89 98
425	15 75	102 83	67 42	82 73

where BHN = Matenal Hardness
D O C = Depths of Cut
Tool Matenals
H S S T. = Hıgh Speed Steel Tool
C T C = Carbıde Tool-Coated
C T U B = Carbıde Tool-Uncoated Brazed
C T.U I = Carbıde Tool-Uncoated ındexable

Table 5.25 Fuzzy Cutting Speed for Medium Carbon Leaded Steel (Model-2)

D.O.C. = 8 m.m.

(BHN)	H.S.S.T	C.T.C.	C.T.U.B.	C.T.U.I.
125	33 73	159 67	100 32	130 82
150	31 73	153 17	96 32	125 82
175	29 73	146 67	92 32	120 82
200	27 73	140 17	88 32	115 82
225	25 73	133 67	84 32	110 82
250	23 73	127 17	80 32	105 82
275	21 73	120 67	76 32	100 82
300	19 73	114 17	72 32	95 82
325	17 73	107 67	68 32	90 82
350	15 73	101 17	64 32	85 82
375	13 73	94 67	60 32	80 82
400	11 73	88 17	56 32	75 82
425	9 73	81 67	52 32	70 82

where BHN = Material Hardness
D O C = Depths of Cut

Tool Materials:
H S S T = High Speed Steel Tool
C T C = Carbide Tool-Coated
C T U B = Carbide Tool-Uncoated Brazed
C T U I = Carbide Tool-Uncoated indexable

Table 5.26 Equations for Medium Carbon Leaded Steel

Tool Material used	Equation	
High Speed Steel Tool	y = 69 81 - 0 12x	DOC = 1mm
	y = 54 00 - 0 09x	DOC = 4mm
	y = 43 80 - 0 08x	DOC = 8mm
Carbide Tool-Coated	y = 373 50 - 0 50x	DOC = 1mm
	y = 247 33 - 0 34x	DOC = 4mm
	y = 192 17 - 0 26x	DOC = 8mm
Carbide Tool-Uncoated Brazed	y = 205 22 - 0 28x	DOC = 1mm
	y = 156 67 - 0 21x	DOC = 4mm
	y = 120 32 - 0 16x	DOC = 8mm
Carbide Tool-Uncoated indexable	y = 264 45 - 0 35x	DOC = 1mm
	y = 205 98 - 0 29x	DOC = 4mm
	y = 155 82 - 0 20x	DOC = 8mm

Where DOC = Depth of Cut

Figs 5 34 to 5 45 show the graphical presentation of the results obtained by applying fuzzy model 2 to Medium Carbon Leaded Steel at three different depths of cut (1mm, 4mm, 8mm) and using four different cutting tools From the graphical representation it is evident that although the fuzzy cutting speeds lie reasonably within the lower and upper limits of the experimental data band, in most cases, fuzzy cutting speed values for lower hardness values he closer to the lower data band and the fuzzy cutting speeds for higher hardness values tend to he closer to the upper limit of the experimental data band Comparing the results obtained from both fuzzy models in the metal cutting operation, model 1 produces better presentation showing good correlation with the Machining Data Handbook's recommended cutting speed

Therefore, computer software was developed to implement the fuzzy model 1 to predict the cutting conditions for Freemachining carbon wrought steel (BHN 225-425) and Medium carbon leaded steel (BHN 125-425)

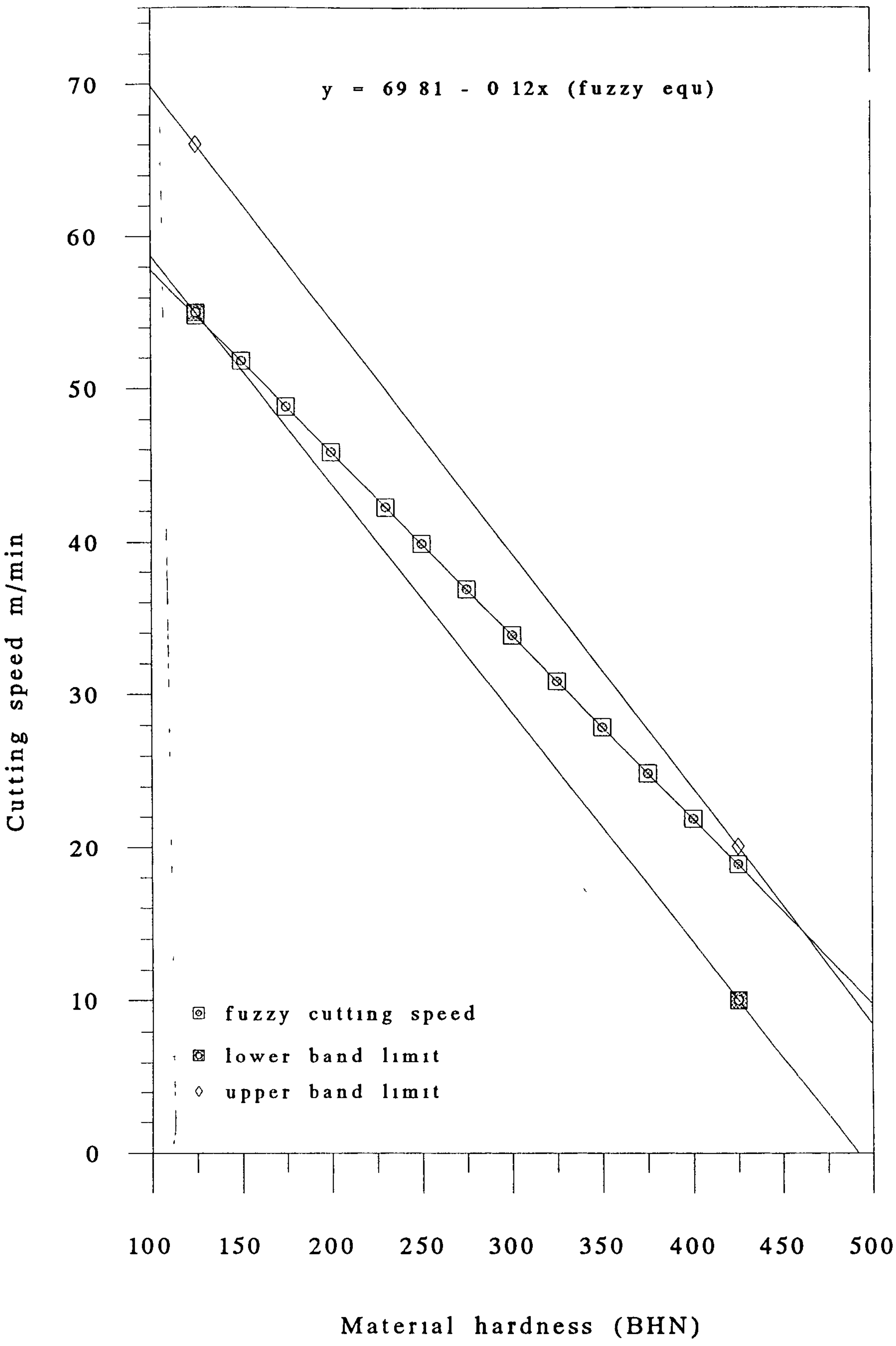


Fig 5.34 Fuzzy cutting speed for Medium carbon leaded steel at d o c 1 mm using High speed steel tool (model-2)

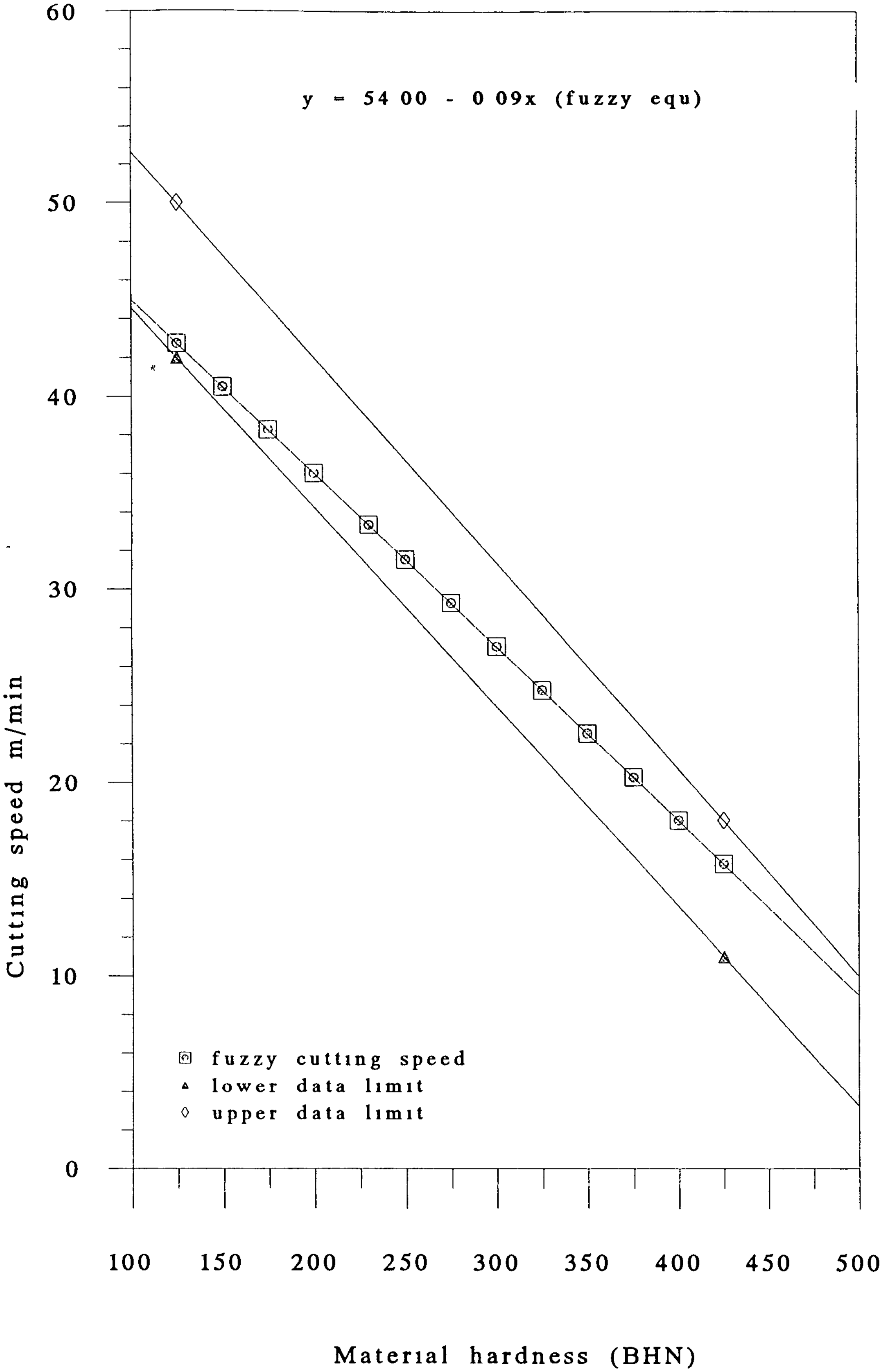


Fig 5.35 Fuzzy cutting speed for Medium carbon leaded steel at d o c 4 mm using High speed steel tool (model-2)

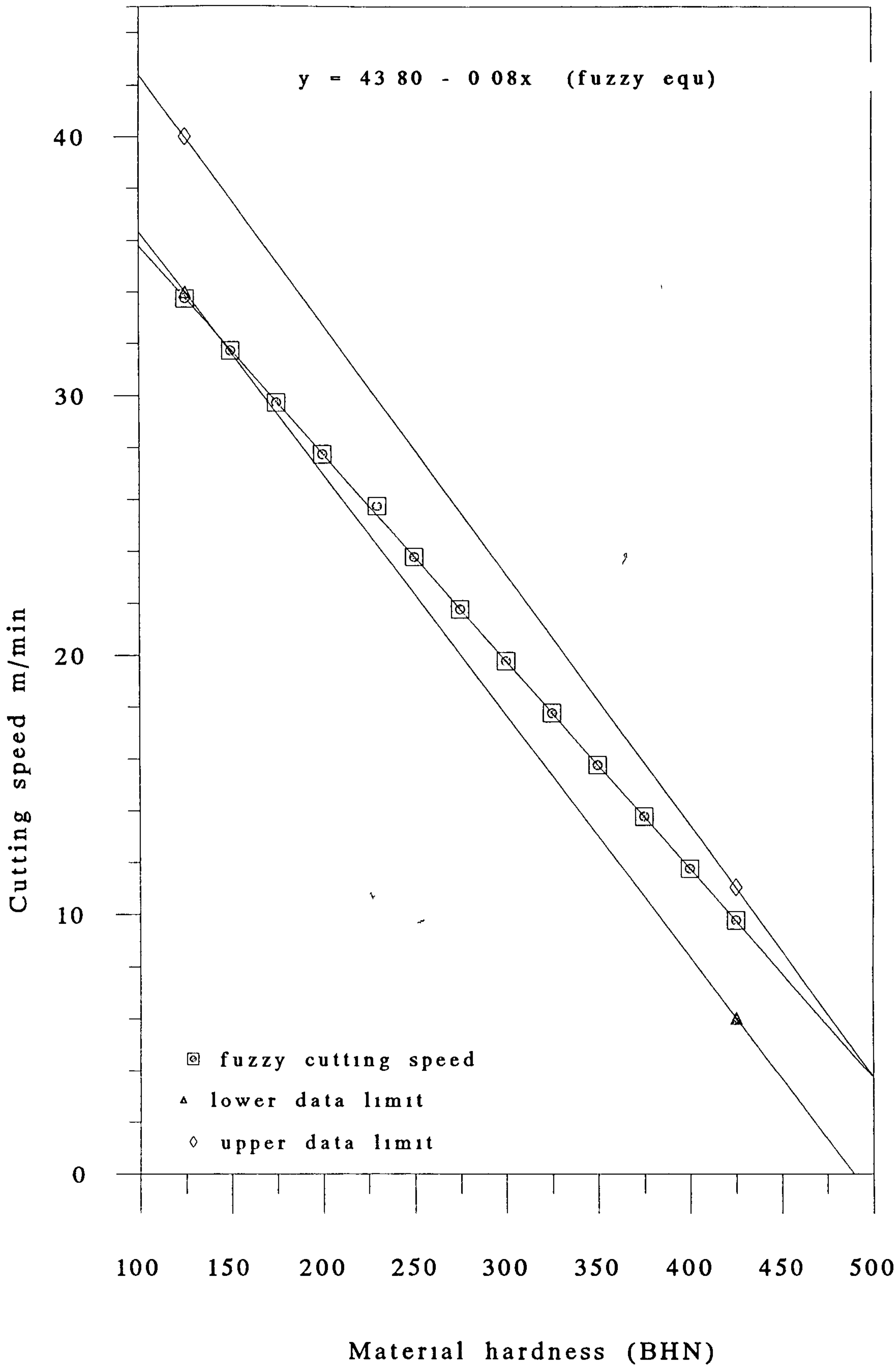


Fig 5 36 Fuzzy cutting speed for Medium carbon leaded steel at d.o.c 8 mm using High speed steel tool (model-2)

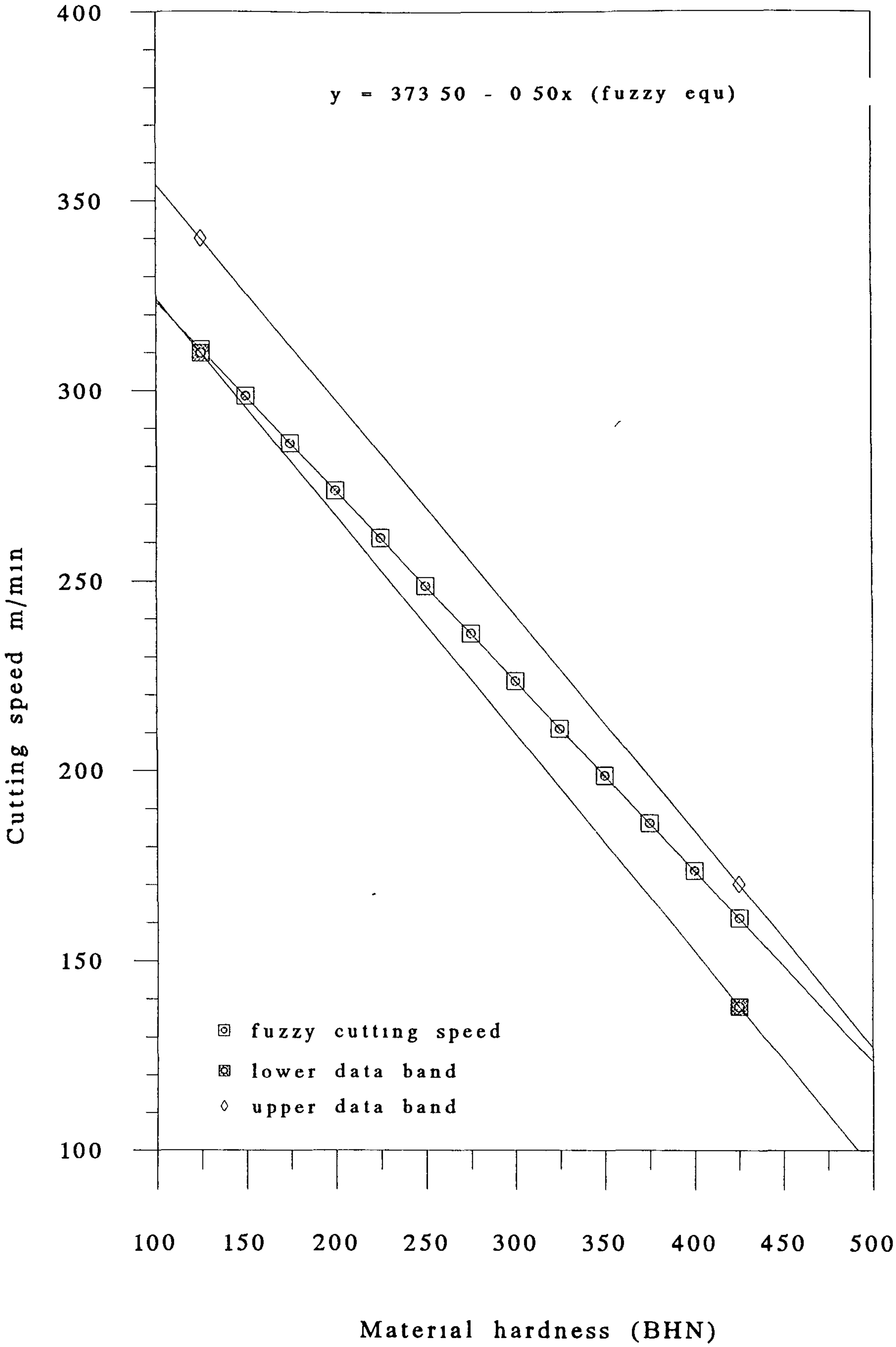


Fig 5.37 Fuzzy cutting speed for Medium carbon leaded steel at d o c 1 mm using Carbide tool-coated (model-2)

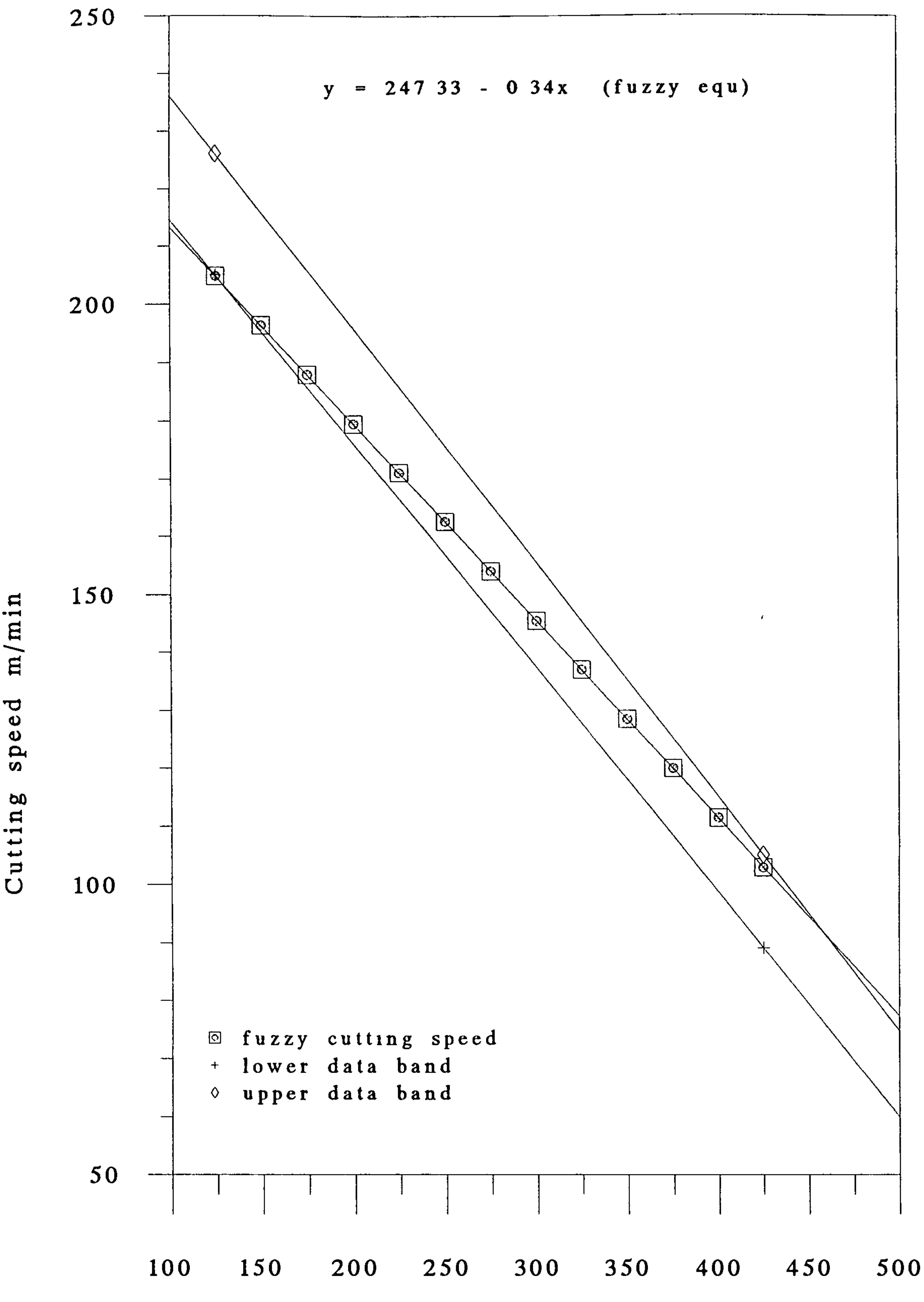


Fig 5.38 Fuzzy cutting speed for Medıum carbon leaded steel at d o c 4 mm using a Carbıde tool-coated (model-2)

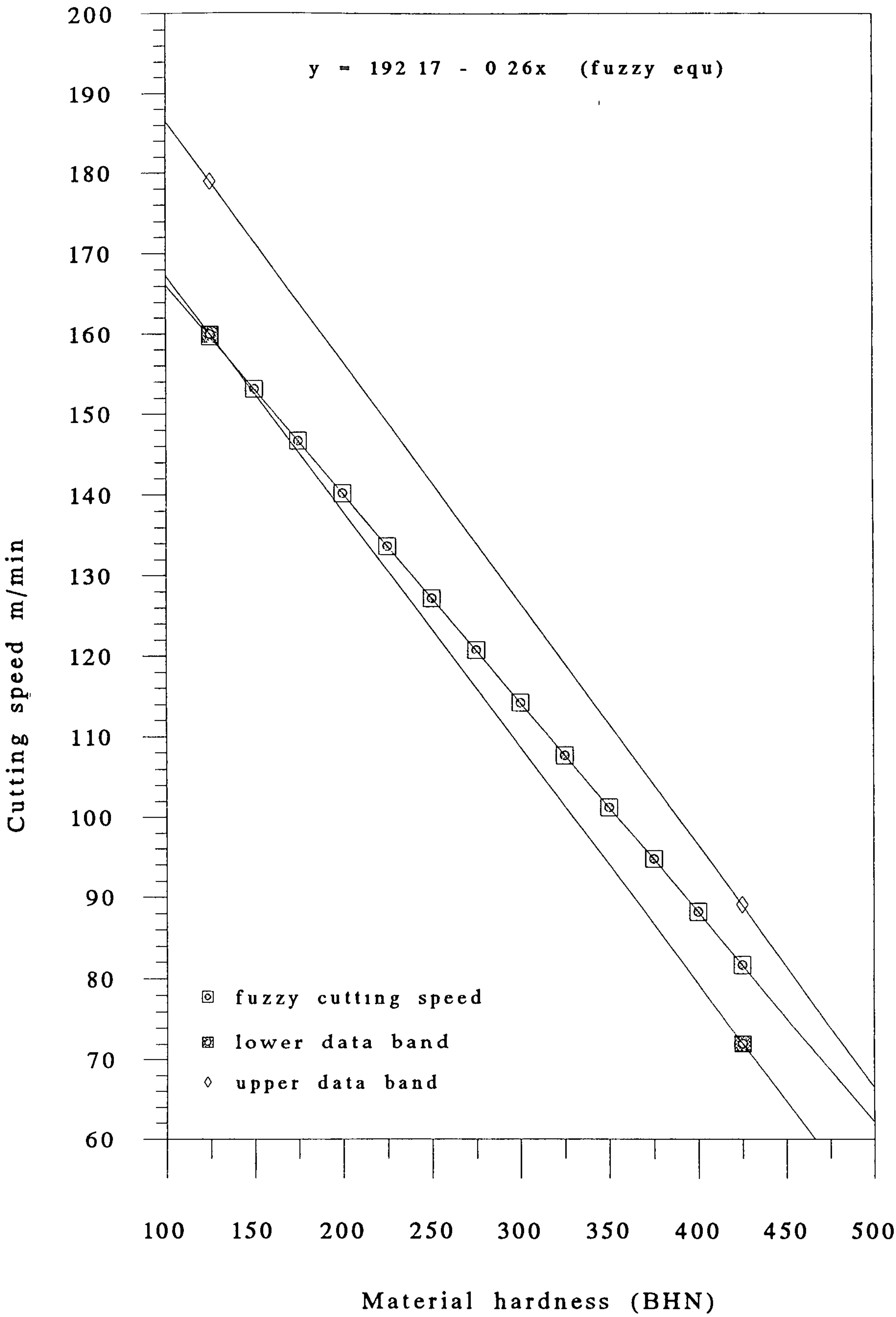


Fıg 5.39 Fuzzy cuttıng speed for Medium carbon leaded steel at d.o.c 8 mm using a Carbıde tool-coated (model-2)

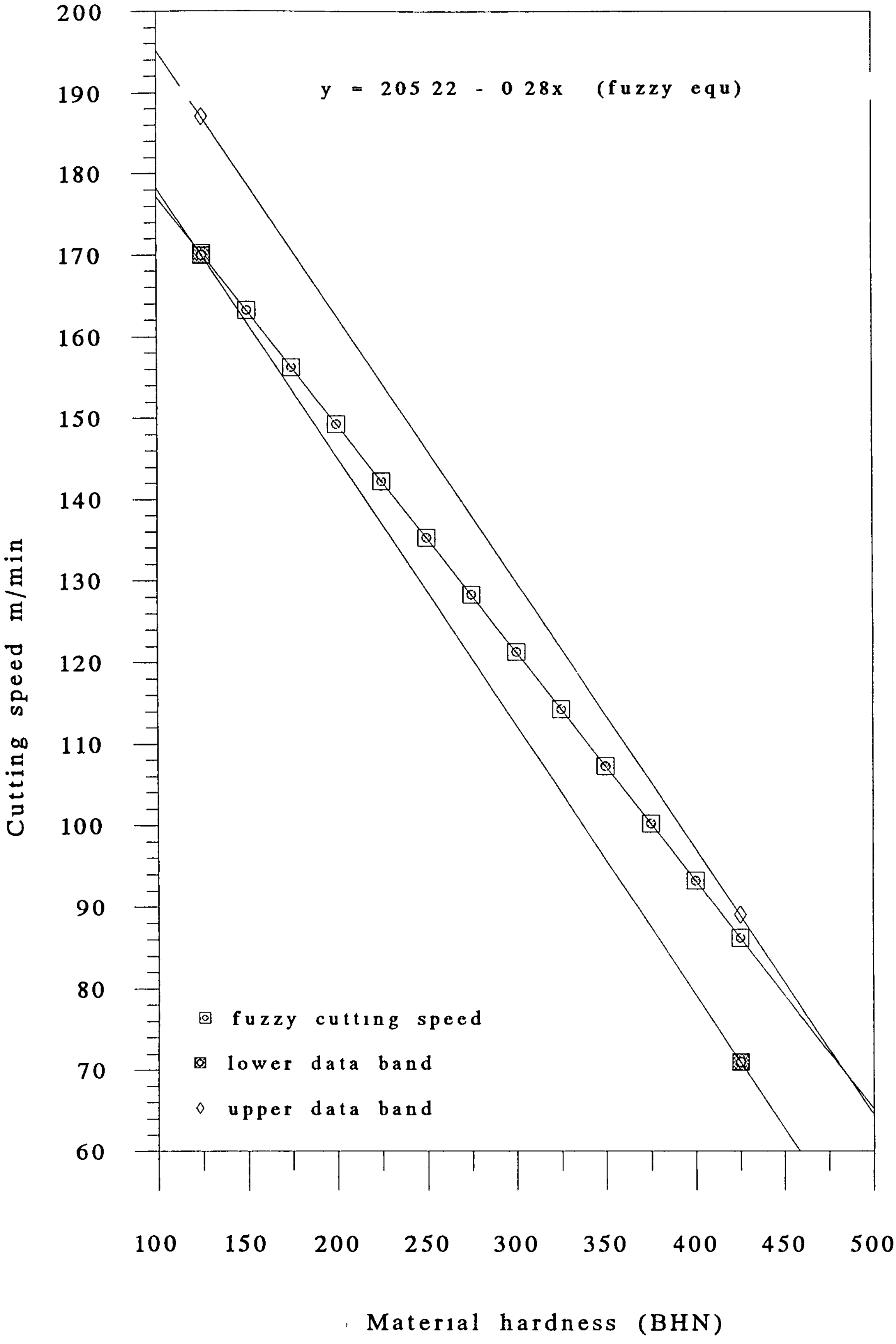


Fıg 5 40 Fuzzy cutting speed for Medium carbon leaded steel at d.o.c 1 mm using a Carbide tool-uncoated brazed (model-2)

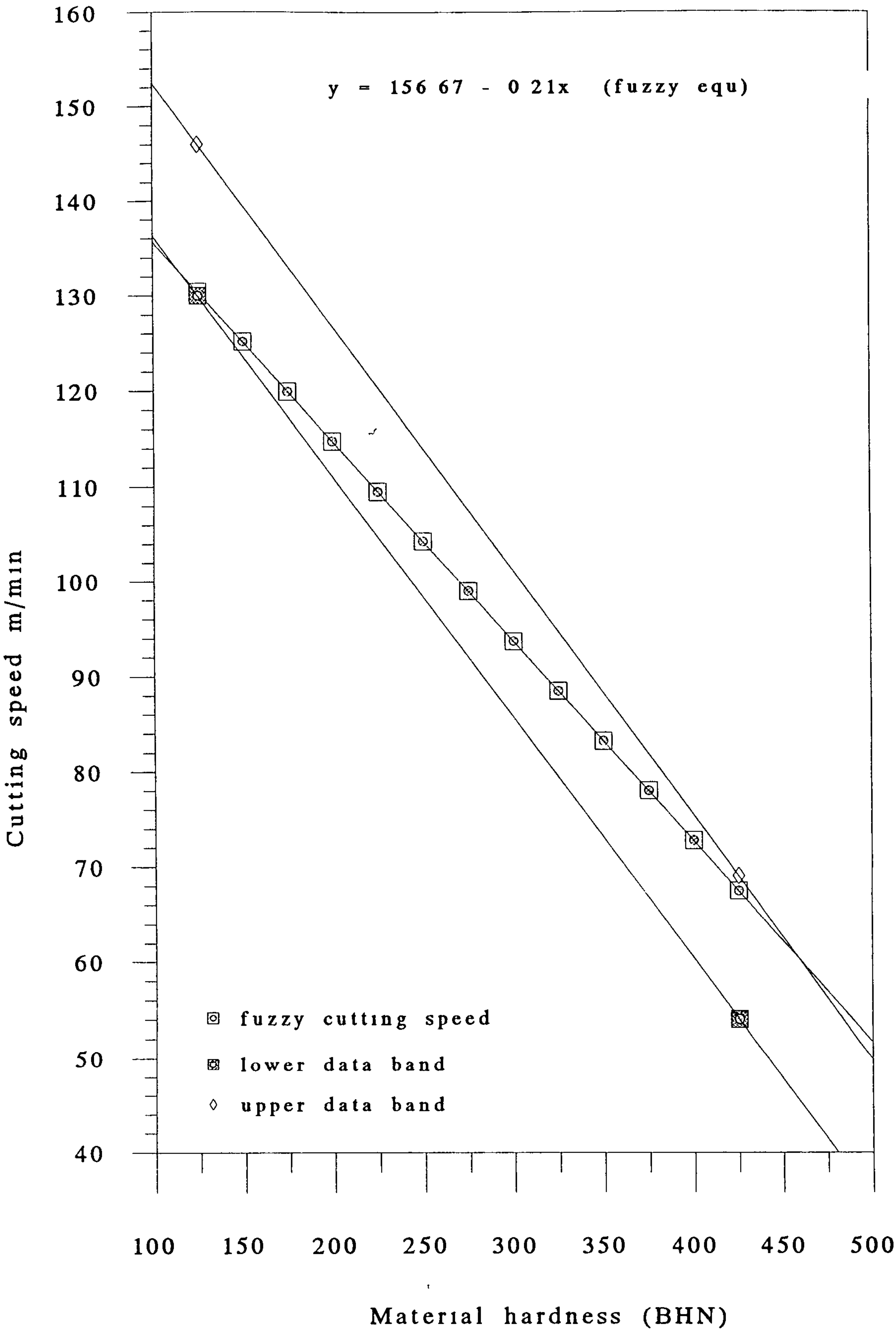


Fig 5.41 Fuzzy cutting speed for Medium carbon leaded steel at d o c 4 mm using a Carbide tool-uncoated brazed (model-2)

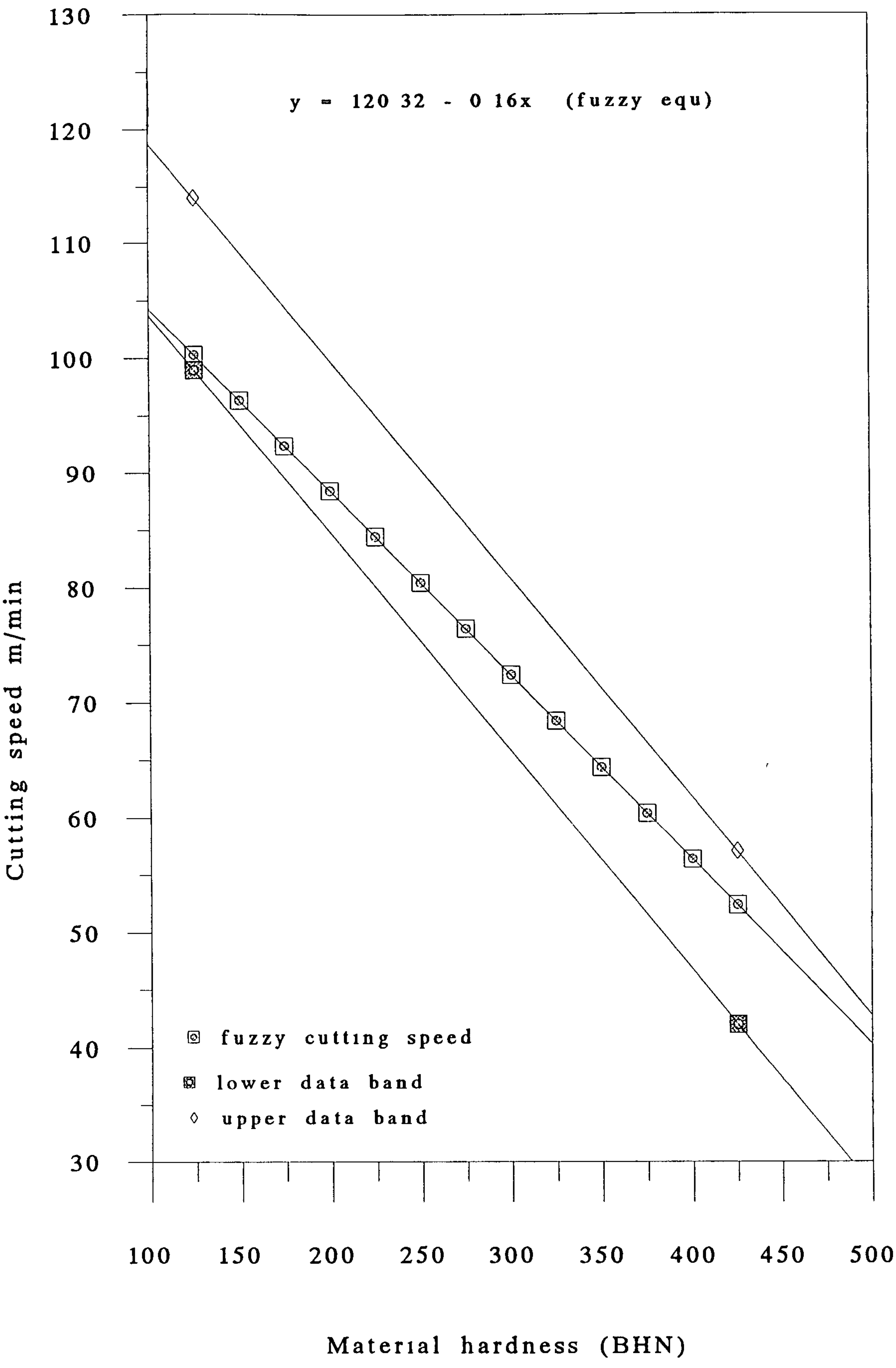


Fig 5.42 Fuzzy cutting speed for Medium carbon leaded steel at d o c 8 mm using a Carbide tool-uncoated brazed (model-2)

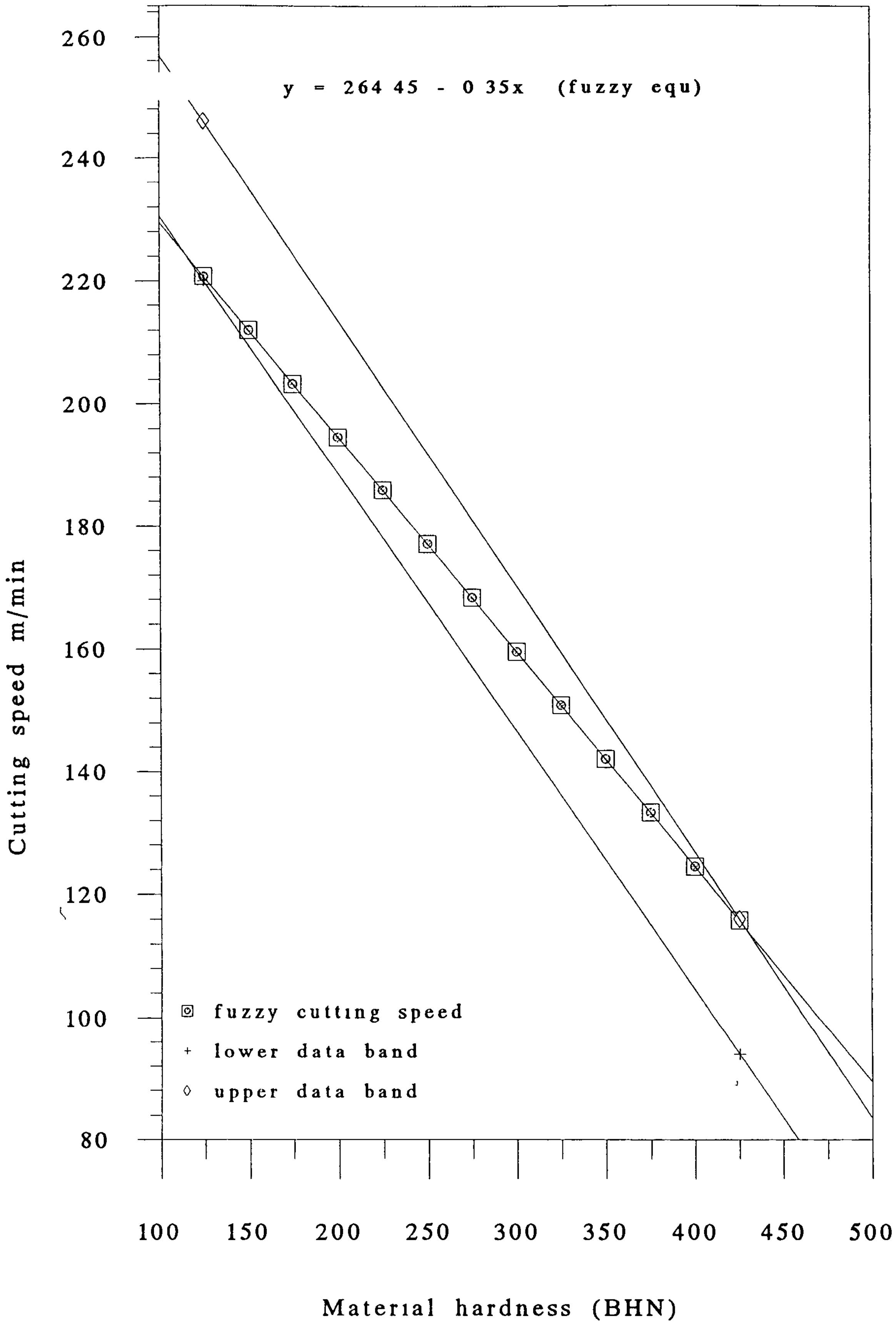


Fig 5.43 Fuzzy cutting speed for Medium carbon leaded steel at d o c 1 mm using a Carbide tool-uncoated indexable (model-2)

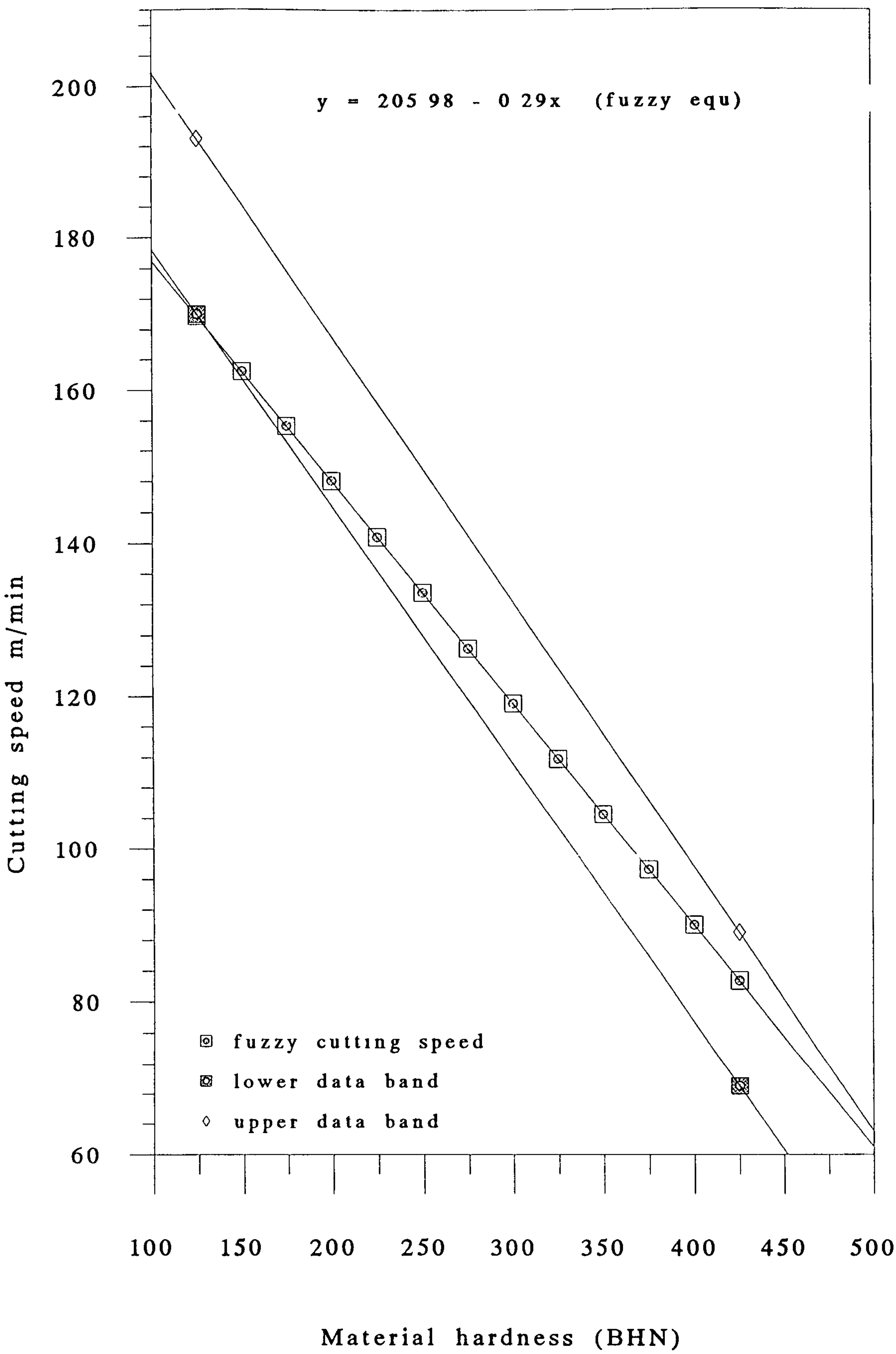
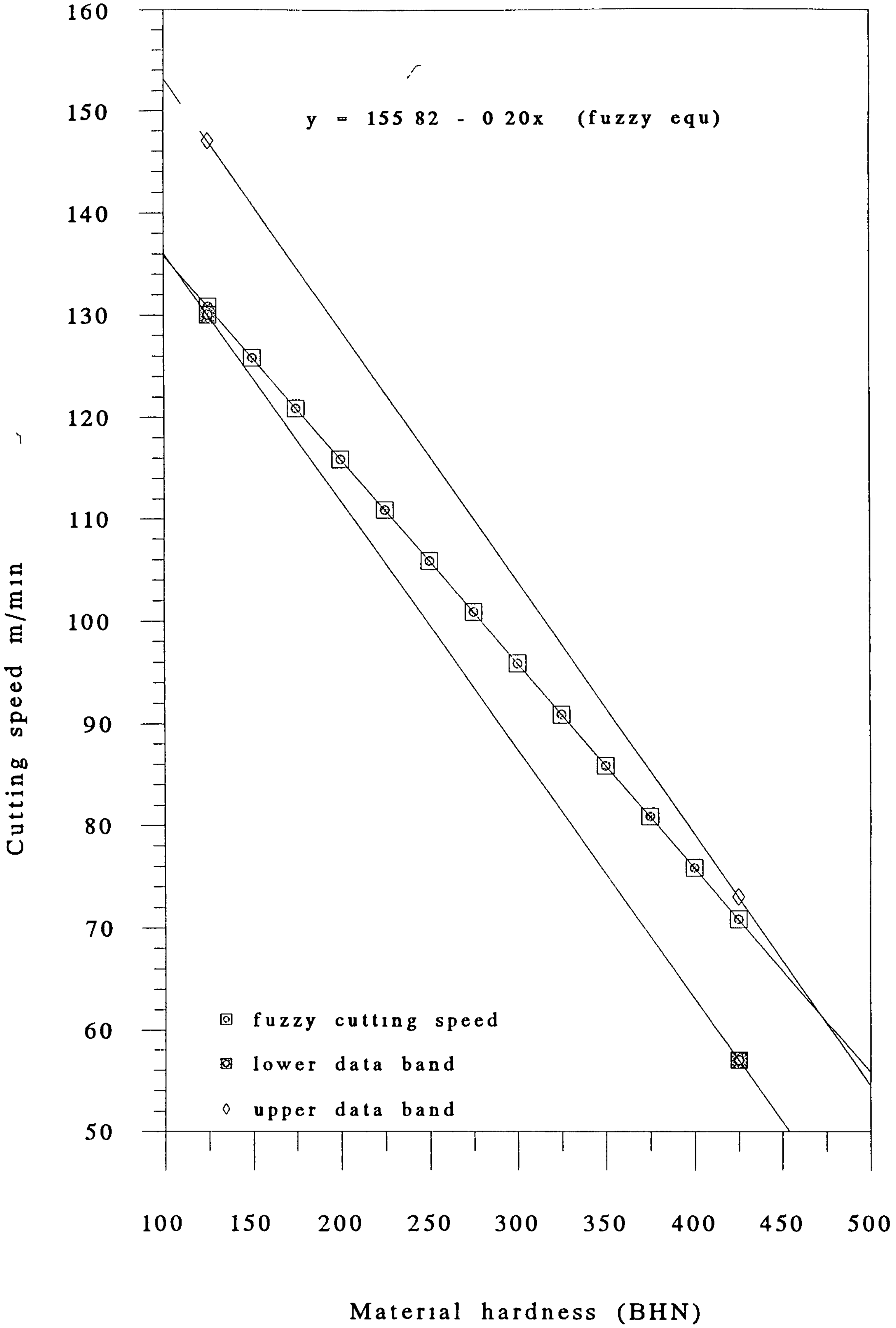


Fig 5.44 Fuzzy cutting speed for Medium carbon leaded steel at d o c 4 mm using a Carbide tool-uncoated indexable (model-2)



Fif 5.45 Fuzzy cutting speed for Medium carbon leaded steel at d o c 8 mm using a Carbide tool-uncoated indexable (model-2)

CHAPTER 6

6.1 Fuzzy Logic Simulation Program for Machining Data Selection.

A computer program has been developed in QBASIC to facilitate automatic selection of cutting speed for known cutting tool, surface finish and hardness of material to be cut. There are two main modules in the program.

(i) DISPLAYMENU is for the programmer to incorporate data for new material.

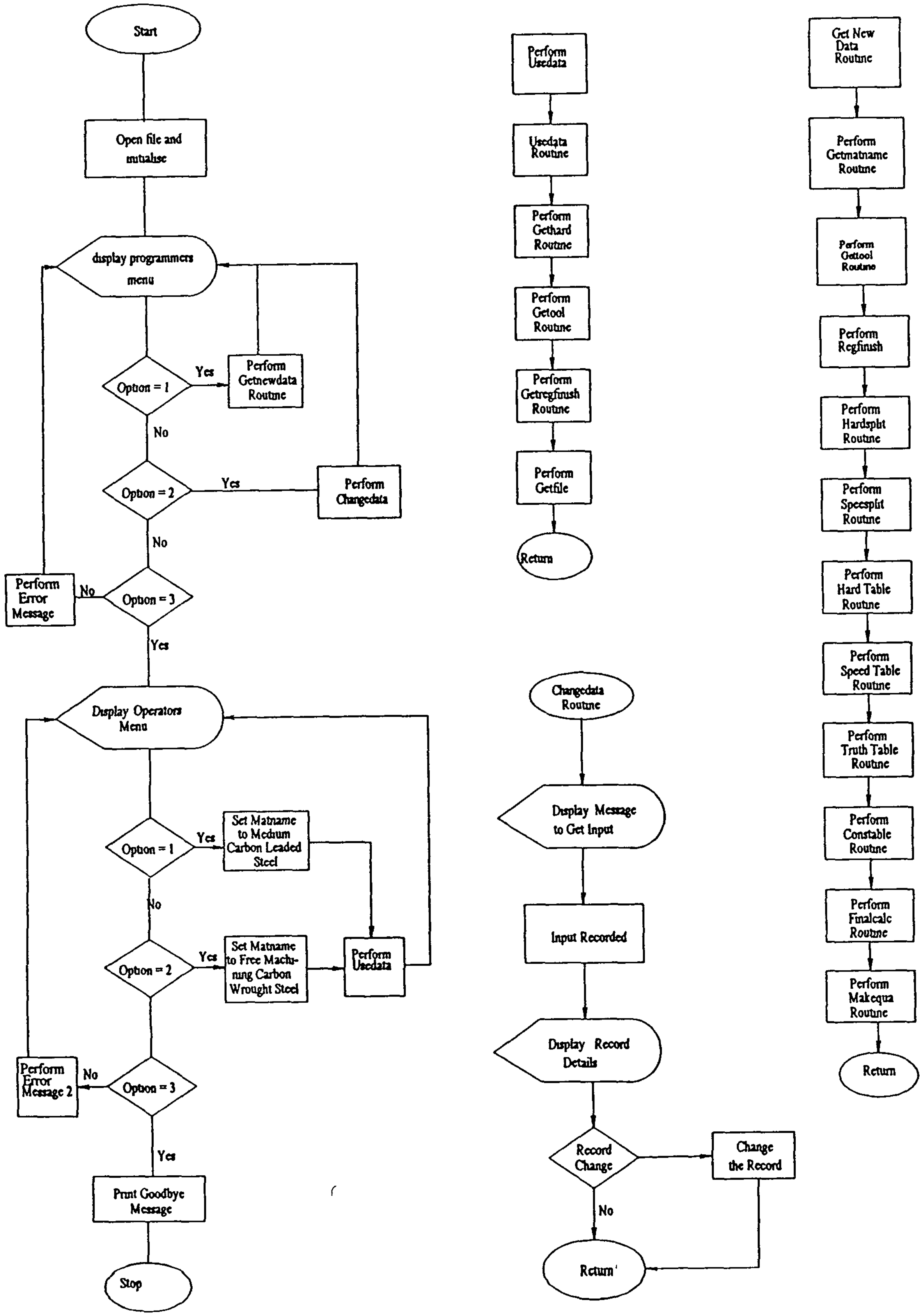
(ii) USERMENU is for the operator to use for data selection.

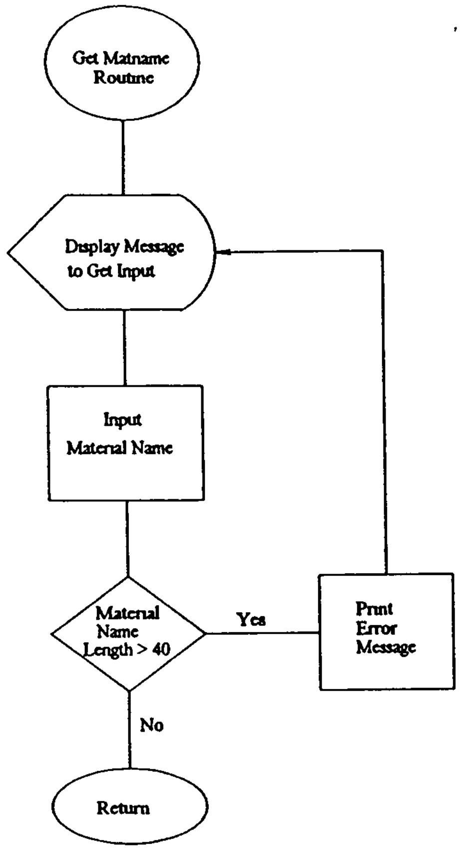
When the DISPLAYMENU is activated, it allows the user to input a new material name, tool name, and depth of cut. It also takes the material hardness ranges and cutting speed ranges. From these input data the membership function for each fuzzy set for hardness and speed are calculated and descritized universe of metal hardness and cutting speed are created in an array form. From these two descritized universe of metal hardness and cutting speed, a fuzzy relational table has been established. An average constant speed table has been created from this fuzzy relation table and stored in an array form. The actual cutting speed has been calculated for each hardness value, based on a known cutting tool and depth of cut. Using these hardness values and cutting speeds, equations have been established employing least square curve fitting method and the relevant parameters have been stored in a random access file called "Tool DAT".

When the USERMENU is activated it offers the operator two types of material that are available on the system for machining data selection. It allows the operator to input metal hardness, his choice of tool and the required surface finish. Appropriate program module takes this data and starts searching for the corresponding equation in the file Tool.DAT and calculates the cutting speed and also displays the cutting conditions on the screen for the operator. This USERMENU has been designed with a do-loop manner so that the operator can obtain the cutting conditions as many times as required for different input data. As two materials, four different types of tools and three different depths of cut were used for this research, there are 24 different records stored in the file Tool.DAT. This software has been designed in a modular fashion to perform different tasks independently. A full program listing can be seen in Appendix while a flow chart is given at Section 6.2

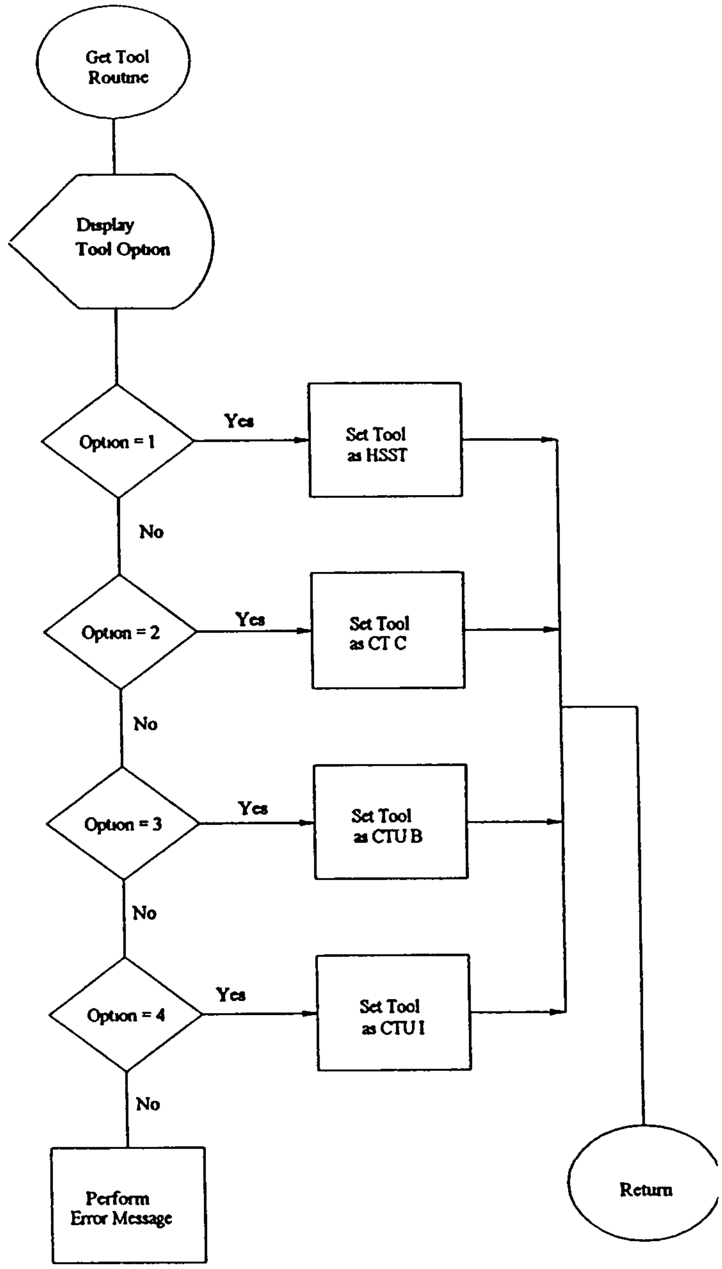
Using this software, calculations have been carried out to obtain the cutting conditions in terms of cutting speed and depth of cut for different types of cutting tool materials. This software also determines the relationship between the hardness value of the material and the cutting speed and stores them in a random access file. Therefore, it facilitates the operator to determine the cutting conditions for any hardness value for two materials (i) medium carbon-leaded steel and (ii) freemachining carbon wrought steel. The results obtained by using this software are shown in the tables and figures in chapter five

6.2 Flow Chart of the Fuzzy Software

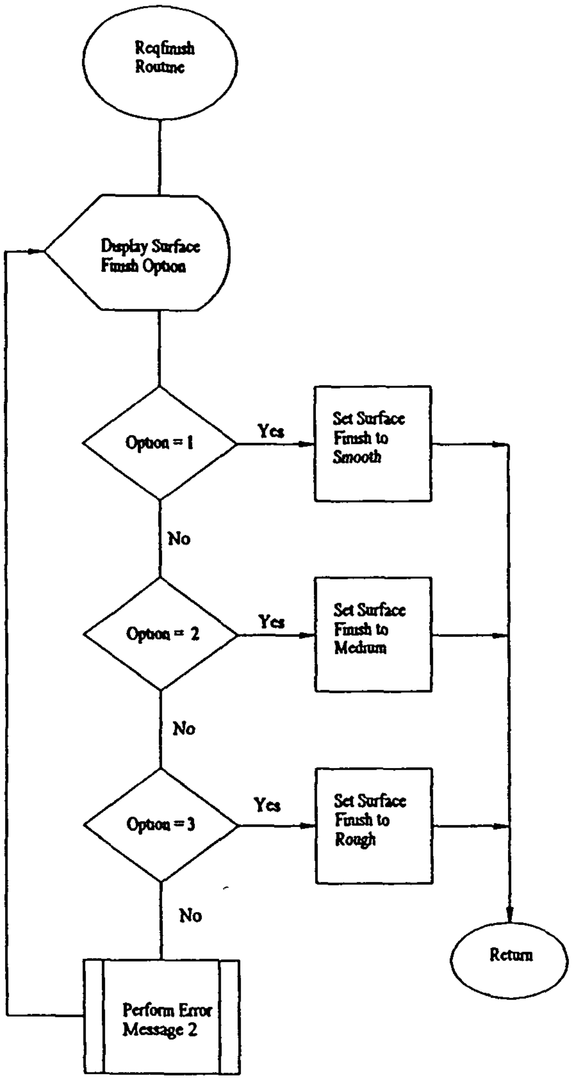


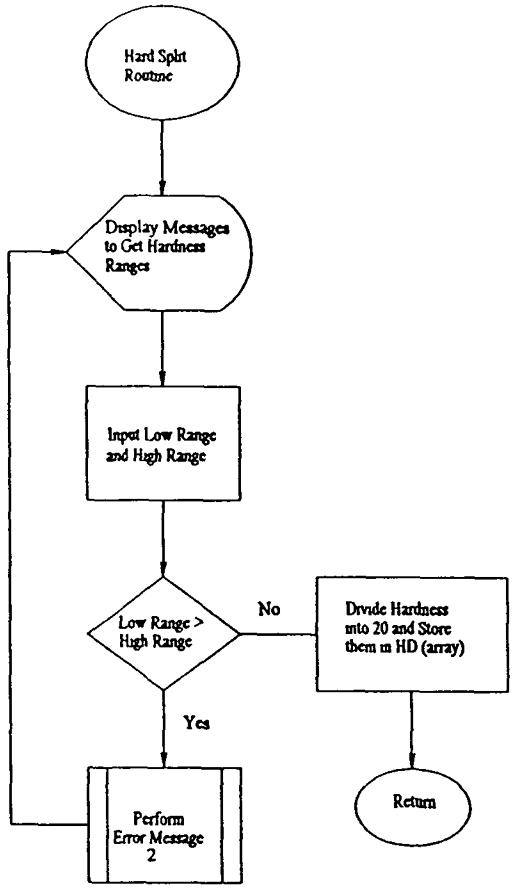


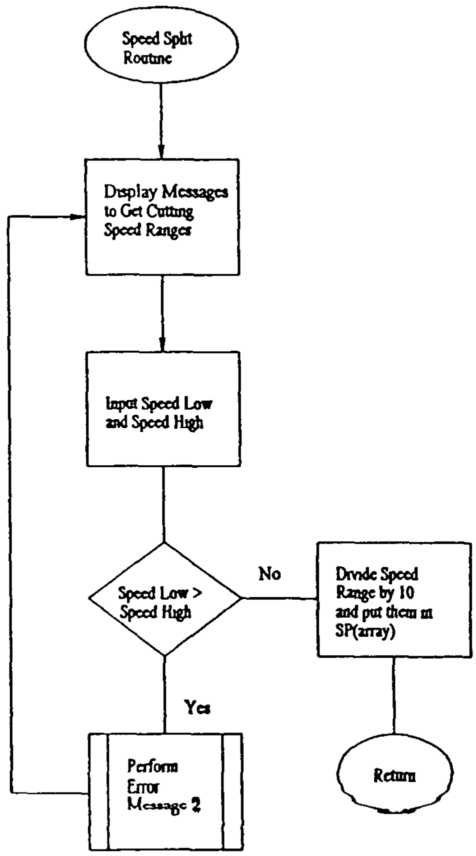
Get Matname Routine
Display Message to Get Input
Input Material Name
Material Name Length > 40
Yes
Print Error Message
No
Return

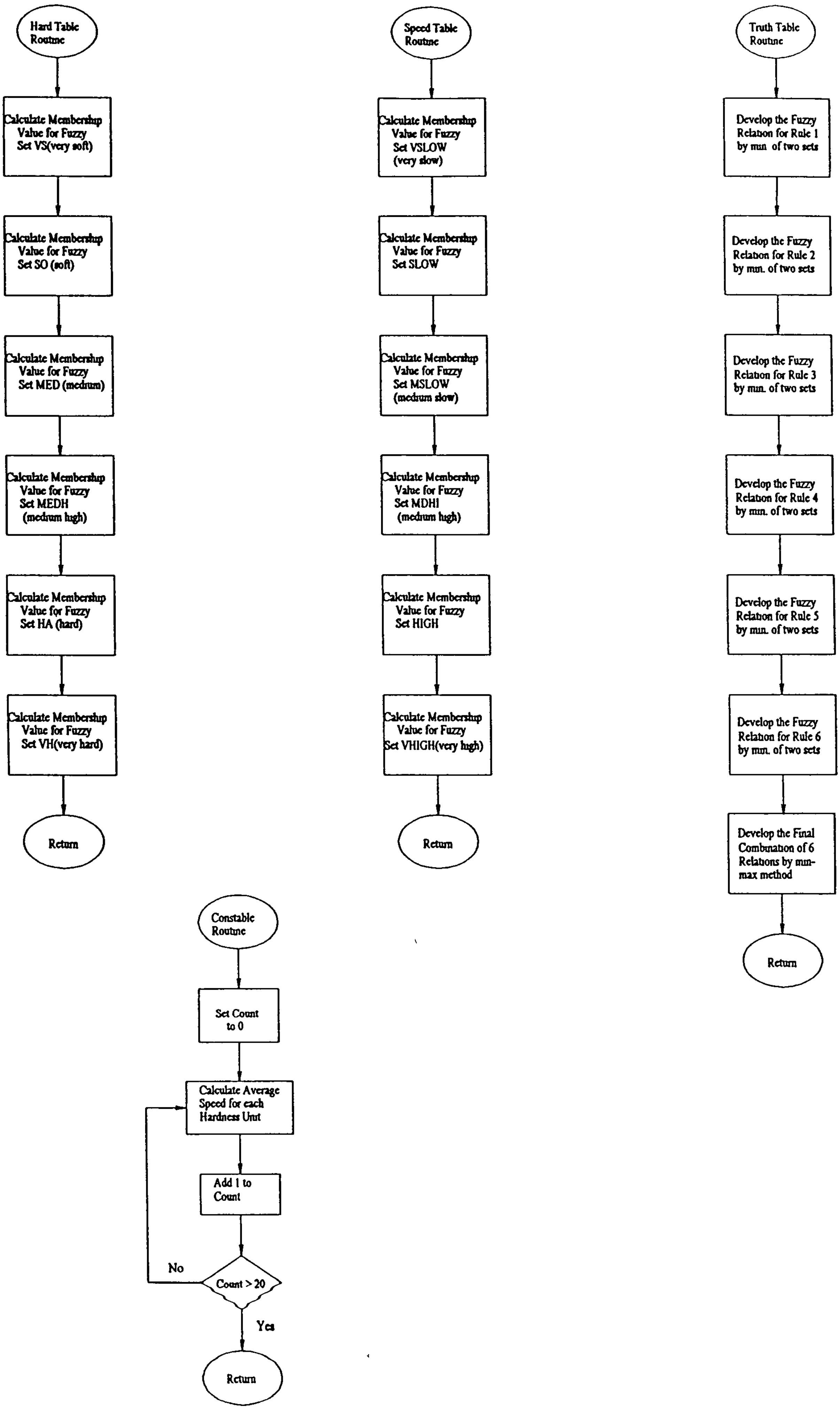


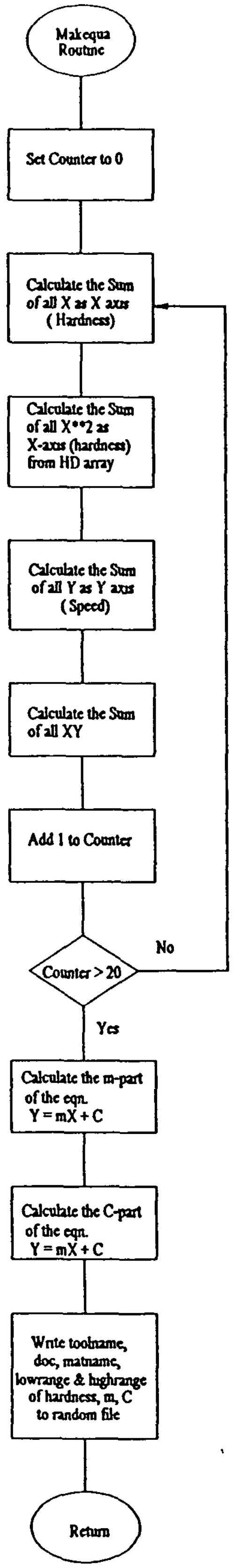
Get Tool Routine
Display Tool Option
Option = 1
Yes
Set Tool as HSST
No
Option = 2
Yes
Set Tool as CT C
No
Option = 3
Yes
Set Tool as CTU B
No
Option = 4
Yes
Set Tool as CTU I
No
Perform Error Message
Return

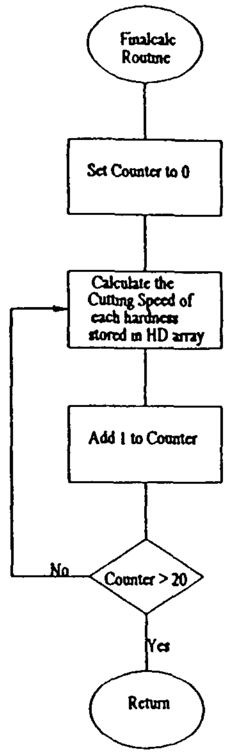

Reqfinish Routine
Display Surface Finish Option
Option = 1
Yes
Set Surface Finish to Smooth
No
Option = 2
Yes
Set Surface Finish to Medium
No
Option = 3
Yes
Set Surface Finish to Rough
No
Perform Error Message 2
Return

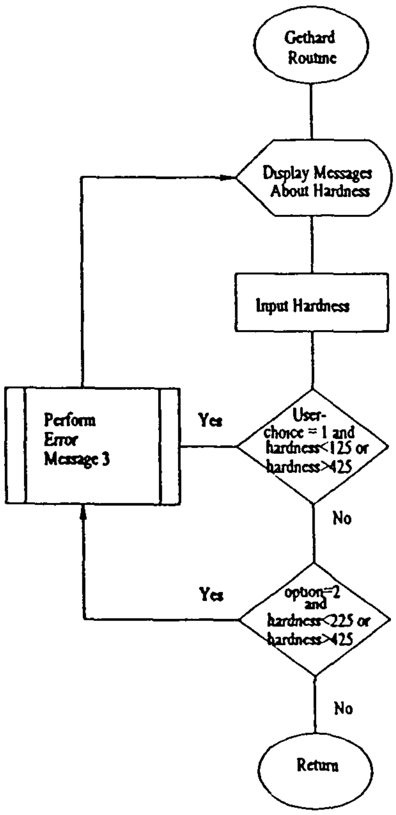

Hard Split Routine
Display Messages to Get Hardness Ranges
Input Low Range and High Range
Low Range > High Range
No
Divide Hardness into 20 and Store them in HD (array)
Yes
Perform Error Message 2
Return

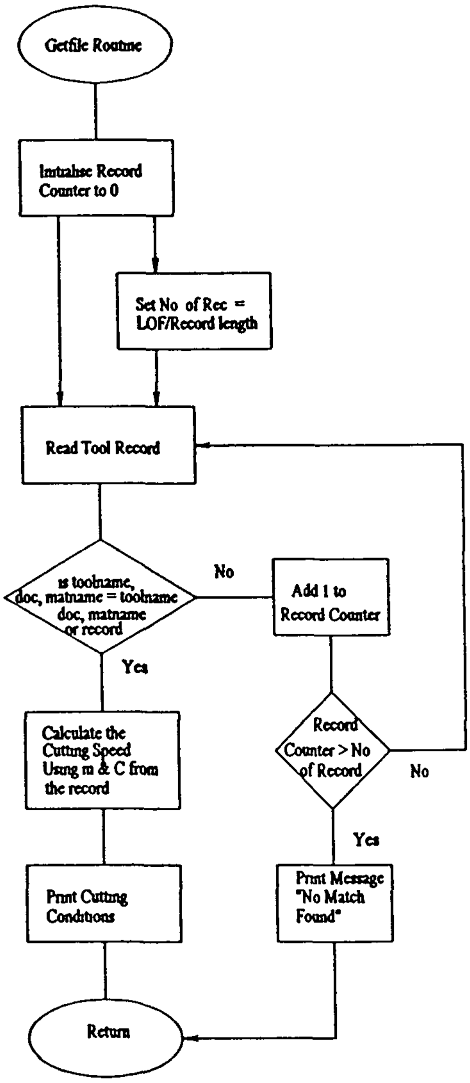

Speed Split Routine
Display Messages to Get Cutting Speed Ranges
Input Speed Low and Speed High
Speed Low > Speed High
No
Divide Speed Range by 10 and put them in SP(array)
Yes
Perform Error Message 2
Return


Hard Table Routine
Calculate Membership Value for Fuzzy Set VS(very soft)
Calculate Membership Value for Fuzzy Set SO (soft)
Calculate Membership Value for Fuzzy Set MED (medium)
Calculate Membership Value for Fuzzy Set MEDH (medium high)
Calculate Membership Value for Fuzzy Set HA (hard)
Calculate Membership Value for Fuzzy Set VH(very hard)
Return
Speed Table Routine
Calculate Membership Value for Fuzzy Set VSLOW (very slow)
Calculate Membership Value for Fuzzy Set SLOW
Calculate Membership Value for Fuzzy Set MSLOW (medium slow)
Calculate Membership Value for Fuzzy Set MDHI (medium high)
Calculate Membership Value for Fuzzy Set HIGH
Calculate Membership Value for Fuzzy Set VHIGH(very high)
Return
Truth Table Routine
Develop the Fuzzy Relation for Rule 1 by min of two sets
Develop the Fuzzy Relation for Rule 2 by min. of two sets
Develop the Fuzzy Relation for Rule 3 by min. of two sets
Develop the Fuzzy Relation for Rule 4 by min. of two sets
Develop the Fuzzy Relation for Rule 5 by min. of two sets
Develop the Fuzzy Relation for Rule 6 by min. of two sets
Develop the Final Combination of 6 Relations by min-max method
Return
Constable Routine
Set Count to 0
Calculate Average Speed for each Hardness Unit
Add 1 to Count
Count > 20
No
Yes
Return


Makequa Routine
Set Counter to 0
Calculate the Sum of all X as X axis (Hardness)
Calculate the Sum of all X**2 as X-axis (hardness) from HD array
Calculate the Sum of all Y as Y axis (Speed)
Calculate the Sum of all XY
Add 1 to Counter
Counter > 20
No
Yes
Calculate the m-part of the eqn. Y = mX + C
Calculate the C-part of the eqn. Y = mX + C
Write toolname, doc, matname, lowrange & highrange of hardness, m, C to random file
Return


Finalcalc Routine
Set Counter to 0
Calculate the Cutting Speed of each hardness stored in HD array
Add 1 to Counter
No
Counter > 20
Yes
Return


Gethard Routine
Display Messages About Hardness
Input Hardness
Perform Error Message 3
Yes
User-choice = 1 and hardness<125 or hardness>425
No
Yes
option=2 and hardness<225 or hardness>425
No
Return


Getfile Routine
Initialise Record Counter to 0
Set No of Rec = LOF/Record length
Read Tool Record
is toolname, doc, matname = toolname doc, matname of record
No
Yes
Add 1 to Record Counter
Record Counter > No of Record
No
Yes
Calculate the Cutting Speed Using m & C from the record
Print Cutting Conditions
Print Message "No Match Found"
Return

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion.

A Fuzzy logic based model was employed for selecting cutting conditions in machining operations Two materials, medium carbon leaded steel and freemachining carbon wrought steel were used at three different depths of cut (1mm, 4mm and 8mm) for theoretical calculations based on experimental data Four different types of cutting tools were used for theoretical calculations and they were i) High Speed Steel Tool, ii) Carbide tool-uncoated, iii) carbide tool-uncoated brazed and iv) carbide tool-uncoated indexable

- Two fuzzy models were developed for these calculations In Model - 1 fuzzy sets were overlapped at 50% and in model-2 fuzzy sets were overlapped at 33%

- Computer software was developed to implement the fuzzy logic principles and to produce the cutting conditions for machining operations automatically

- Fuzzy model 1 produces theoretical results which fits better with the experimental data than the results obtained using model 2

- In both models the fuzzy cutting speeds in terms of different cutting conditions, lie within the lower and upper limits of the experimental data bands

- Equations have been established between the hardness values and fuzzy cutting speed values

- Results show that the fuzzy logic method can be used satisfactorily to present the cutting conditions in a compressed way
- It has been assumed that the cutting speed obtained using fuzzy logic principles would produce better cutting results in terms of either better

surface finish, or lower cutting force or longer tool life Experimental work will be necessary to be carried out in order to verify this assumptions However such experimental works were beyond the scope of the present study

7.2 Recommendations for Further Work

In this study only two materials were used Experimental data for other materials could also be represented by the fuzzy logic model

Experimental works should be carried out to verify the predicted results obtained by employing the fuzzy logic models

Experimental works should be carried out to verify the fuzzy logic predictions in terms of satisfactory surface quality

In this study, the hardness of the workpiece has been used as the only material property Other material properties which have significant effect on the machining quality of the workpiece material, for example material toughness (ductility/brittleness) should be considered

A fuzzy logic model can be developed based on a minimum of two such mechanical properties (hardness and ductility) and used as a predictive tool for machining conditions for new materials for which there is no experimental data currently existing

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APPENDIX

Programme Listing

Fuzzy.bas

Program Name	:	FUZZY
Purpose	:	Provides a Fuzzy Logic based approach
	:	to selecting machining parameters
Author	·	Ms Kashmeri Hashmi
Context	:	Submitted as part of thesis for the award M Sc in Computer Applications
Language used	:	QBASIC
System requirements	:	IBM PC or equivalent running MS-DOS
Date Completed	:	20 March 1997
Version	:	1 00

```
'    Subroutines used are declared below

     DECLARE SUB CHANGEDATA ()
     DECLARE SUB TESTING ()
     DECLARE SUB ERRORMESSAGE1 ()
     DECLARE SUB ERRORMESSAGE2 ()
     DECLARE SUB OPMENU ()
     DECLARE SUB GETTOOL ()
     DECLARE SUB GETREQFINISH ()
     DECLARE SUB MAIN MENU ()
     DECLARE SUB ERRORMESSAGE3 ()
     DECLARE SUB GETMATNAME ()
     DECLARE SUB DISPLAYMENU ()
     DECLARE SUB USERMENU ()
     DECLARE SUB GETNEWDATA ()
     DECLARE SUB HARDSPLIT ()
     DECLARE SUB SPEEDSPLIT ()
     DECLARE SUB HARDTABLE ()
     DECLARE SUB SPEEDTABLE ()
     DECLARE SUB TRUTHTABLE ()
     DECLARE SUB CONSTABLE ()
     DECLARE SUB FINALCALC ()
     DECLARE SUB MAKEQUA ()
     DECLARE SUB USEDATA ()
     DECLARE SUB GETNAME ()
     DECLARE SUB GETHARD ()
     DECLARE SUB GETFILE ()
     DECLARE SUB ERRORMESSAGE ()

'    End of declaration of all the subroutines

'    Array used

     DIM SHARED    hd(20)               AS SINGLE
     DIM SHARED    SP(10)               AS SINGLE
     DIM SHARED    HARD(5, 20)          AS SINGLE
     DIM SHARED    SPEED(5, 10)         AS SINGLE
     DIM SHARED    FINALTABLE(20, 10)   AS SINGLE
     DIM SHARED    CONSPEED(20)         AS SINGLE
     DIM SHARED    ACULSPEED(20)        AS SINGLE
'    End of reserving all the arrays for future use
```

```
'   Declaration of shared variables

    COMMON SHARED choice         AS INTEGER
    COMMON SHARED lowrange       AS INTEGER
    COMMON SHARED highrange      AS INTEGER
    COMMON SHARED highspeed      AS INTEGER
    COMMON SHARED lowspeed       AS INTEGER
    COMMON SHARED doc            AS INTEGER
    COMMON SHARED result         AS SINGLE
    COMMON SHARED userchoice     AS INTEGER
    COMMON SHARED toolname       AS STRING * 40
    COMMON SHARED matname        AS STRING * 40
    COMMON SHARED finish         AS STRING * 15
    COMMON SHARED hardness       AS SINGLE
    COMMON SHARED cutspeed       AS SINGLE


'   End of declaration of all common shared variables

'   Define record layout

    TYPE toolrec
      mname           AS STRING * 40
      tname           AS STRING * 40
      doct            AS INTEGER
      hardlow         AS INTEGER
      equam           AS SINGLE
      equac           AS SINGLE

    END TYPE
    COMMON SHARED cd AS toolrec
'*****************************************************
'   MAIN PROGRAM STARTS HERE


    OPEN "c tool dat" FOR RANDOM AS #1 LEN = 94

'   CALL DISPLAYMENU             'This menu is for programer's use only

    CALL USERMENU                'This menu is for operator only
                                 'to find the cutting conditions
                                 'of a metal
    CLOSE #1

    END                          'End of main program
```

```
SUB CHANGEDATA
********************************************************

'   Subroutine CHANGEDATA
'   Allows the opened data file to be changed
'   The material name in any selected record can be altered

'

    CLS
    R = LOF(1) / LEN(cd)
    PRINT "Total no of records in file Tool dat=", R
    PRINT "***************************************"
    PRINT "Please enter record no to change"
    INPUT recordnum
    GET #1, recordnum, cd
    CLS
    PRINT "Record no ------------", recordnum
    PRINT
    PRINT "Material name ---------", cd mname
    PRINT
    PRINT "Toolname -------------", cd tname
    PRINT
    PRINT "Depth of cut ---------", cd doct
    PRINT
    PRINT "Low hardness ----------", cd hardlow
    PRINT
    PRINT "High hardness ----------", cd hardhigh
    PRINT "*********************************************"
    PRINT "    You can change only material name    "
    PRINT "    To change material name type Y/N     "

    INPUT ans$

    IF (ans$ = "Y") OR (ans$ = "y") THEN
      CALL GETMATNAME
      cd mname = matname$
      PUT #1, recordnum, cd
      CLS
      PRINT "Material name has been changed and stored in Tool dat"
      CALL TESTING
    END IF

  END SUB
```

```
SUB CONSTABLE
'*****************************************************
' Subroutine CONSTABLE
'
'
' Creates the average speed values shown in Table 5 9 in Chap 5
'
   CLS
   FOR i = 0 TO 20
     LET sum = 0
     LET sum1 = 0
     FOR j = 0 TO 10
       sum = sum + FINALTABLE(i, j) * j
       sum1 = sum1 + FINALTABLE(i, j)
     NEXT j

     result = sum / sum1
     conspeed(i) = result
   NEXT i

END SUB

SUB DISPLAYMENU
'****************************************************

' Subroutine DISPLAYMENU
' Displays a menu for use by the system administrator only
'
'
   CLS

   DO
     MAIN MENU
     SELECT CASE choice
       CASE 1
         GETNEWDATA
       CASE 2
         CHANGEDATA
       CASE 3
         PRINT "Thankyou for using fuzzy expert system "
         PRINT "Goodbye "
         PRINT
       CASE ELSE
         ERRORMESSAGE
     END SELECT
   LOOP UNTIL (choice = 3)

END SUB
```

```
   SUB ERRORMESSAGE
'*********************************************************
'
'  Subroutine ERRORMESSAGE
'  Used to display error messeages for DISPLAYMENU
'


     CLS
     PRINT "You must enter 1 or 2 or 3 only "
     PRINT
     PRINT "Please try again  "
     PRINT

   END SUB

   SUB ERRORMESSAGE1
'******************************************************
'
'   Subroutine ERRORMESSAGE1
'   Used to display error messages for GETTOOL
'
'
     CLS

     PRINT
     PRINT "You must enter 1 or 2 or 3 or 4 only"
     PRINT "please try again "
     PRINT


   END SUB

   SUB ERRORMESSAGE2
'*****************************************************
'
'   Subroutine ERRORMESSAGE2
'   Used to display error messages for GETREQFINISH
'
     CLS
     PRINT "You have pressed the wrong key"
     PRINT
     PRINT "Please try again"

   END SUB
```

```
SUB ERRORMESSAGE3
'**********************************************************
'
' Subroutine ERRORMESSAGE3
' Used to display error messages for GETHARD
'

   CLS
   PRINT
   PRINT "You have entered wrong hardness for ", matname$
   PRINT
   PRINT "Please try again                 "
   PRINT

END SUB




SUB FINALCALC
'*******************************************************
'
' Subroutine FINALCALC
' Calculates the final cutting speeds
'
   diff = highspeed - lowspeed
   CLS
   PRINT "Speed difference betwee high and low speed is as follows "
   PRINT "************************************************************"
   PRINT
   PRINT "Speed difference= ", diff
   PRINT
   PRINT
   CALL TESTING

   FOR i = 0 TO 20
     ACULSPEED(i) = conspeed(i) / 10 * diff + lowspeed
   NEXT i


END SUB
```

```
SUB GETFILE

'***************************************************
'  Subroutine GETFILE
'  Opens data file and searches for corresponding record
'  and performs calculations and displays cutting parameters
'  when match is found

    CLS
    PRINT "*********************************************************"
    PRINT
    PRINT "Material name requisted by the operator **", matname$
    PRINT
    PRINT "Hardness of the material *****************", hardness
    PRINT
    PRINT "Toolname requested by the operator *******", toolname$
    PRINT
    PRINT "Surface finish requested for this operation**", finish$
    PRINT "*********************************************************"
    PRINT
    PRINT

    CALL TESTING                    'Holds the screen
    R = LOF(1) / LEN(cd)            'Total number of records
    match = 0
    FOR recnum = 1 TO R
      GET #1, recnum, cd            'Get the next record
       IF (cd mname = matname$)
       AND (cd tname = toolname$)
        AND (cd doct = doc)
        THEN
        cutspeed = (cd equam * hardness) + cd equac
        match = match + 1
        CLS
        PRINT
        PRINT "Cutting parameters for material--------", cd mname
        PRINT
        PRINT "      are as follows            "
        PRINT
        PRINT "For material hardness(BHN)-------------", hardness
        PRINT
        PRINT "Cutting speed(m/min)------------------", cutspeed
        PRINT
        PRINT "Depth of cut(mm)----------------------", cd doct
        PRINT
        PRINT "Cutting tool is-----------------------", cd tname
        PRINT
        CALL TESTING
      END IF
    NEXT recnum
```

```
  IF match = 0 THEN
    CLS
    PRINT "    Matching data not found    "
    PRINT "    ***********************    "
    PRINT
    PRINT
    CALL TESTING
  END IF

END SUB



SUB GETHARD
'*****************************************************
'
'  Subroutine GETHARD
'  accepts material hardness from user
'
entrhard
   CLS
   PRINT "Material hardness (BHN) for MEDIUM CARBON LEADED should        "
   PRINT "be in the range between 125-425                                "
   PRINT
   PRINT "Material hardness (BHN) for FREE MACHINING CARBON WROUGHT "
   PRINT
   PRINT "be in the range between 225---425                              "
   PRINT
   PRINT "Now enter your required hardness                               "
   PRINT
   INPUT hardness
   IF (userchoice = 1) AND ((hardness < 125) OR (hardness > 425)) THEN
     CLS
     CALL ERRORMESSAGE3
     CALL TESTING
     GOTO entrhard
   END IF
   IF (userchoice = 2) AND ((hardness < 225) OR (hardness > 425)) THEN
     CLS
     CALL ERRORMESSAGE3
     CALL TESTING
     GOTO entrhard
   END IF
 END SUB
```

```
    SUB GETMATNAME
'*************************************************
'
'   Subroutine GETMATNAME
'   Accepts new material name from programer
'
       CLS
material
      PRINT "Enter material name please"
      PRINT
      PRINT "Name should be maximum 40 characters long"
      PRINT
      INPUT matname$
      IF LEN(matname$) > 40 THEN
        PRINT "Material name length out of range"
        PRINT
        PRINT "Please try again "
        CALL TESTING
        GOTO material
      END IF

    END SUB



    SUB GETNEWDATA
'*************************************************
'
'   Subroutine GETNEWDATA
'   Develops Fuzzy model step by step for incorporating new data
'
'
      CALL GETMATNAME
      CALL GETTOOL
      CALL GETREQFINISH
      CALL HARDSPLIT
      CALL SPEEDSPLIT
      CALL HARDTABLE
      CALL SPEEDTABLE
      CALL TRUTHTABLE
      CALL CONSTABLE
      CALL FINALCALC
      CALL MAKEQUA

    END SUB
```

```
   SUB GETREQFINISH
'*************************************************
'
'  Subroutine GETREQFINISH
'  Accepts the required surface finish from user selects
'  the depth of cut

     CLS
finishstart
     PRINT "Choose surface finish from the following options   "
     PRINT
     PRINT "For smooth finish type ---------------- S          "
     PRINT
     PRINT "For medium finish type ---------------- M          "
     PRINT
     PRINT "For rough finish type  -----------------R          "
     PRINT
     INPUT sfinish$
     IF (sfinsh$ = "S") OR (sfinish$ = "s") THEN
       doc = 1
       finish$ = "Smooth finish"
     ELSEIF (sfinish$ = "M") OR (sfinish$ = "m") THEN
       doc = 4
       finish$ = "Medium finish"
     ELSEIF (sfinish$ = "R") OR (sfinish$ = "r") THEN
       doc = 8
       finish$ = "Rough finish"

     ELSE
       CALL ERRORMESSAGE2
       CALL TESTING
       GOTO finishstart
     END IF

   END SUB
```

```
   SUB GETTOOL
'*************************************************
'
'  Subroutine GETTOOL
'  Displays choices of tools available on the system and
'  accepts user's choice
'
      CLS
toolstart
      PRINT "Choose cutting tool from the following options              "
      PRINT
      PRINT "For High speed steel (HSS) type --------------------- 1      "
      PRINT
      PRINT "For Carbide tool coated (CTC) type -----------------2      "
      PRINT
      PRINT "For Carbide tool uncoated brazed (CTUB) ----------3      "
      PRINT
      PRINT "For Carbide tool uncoated indexable(CTUI)---------4      "
      PRINT
      INPUT toolnum

      IF (toolnum = 1) THEN
        toolname$ = "high speed steel tool"
      ELSEIF (toolnum = 2) THEN
        toolname$ = "carbide tool coated"
      ELSEIF (toolnum = 3) THEN
        toolname$ = "carbide tool uncoated brazed"
      ELSEIF (toolnum = 4) THEN
        toolname$ = "carbide tool uncoated indexable"
      ELSE
        CALL ERRORMESSAGE1
        CALL TESTING
        GOTO toolstart
      END IF

   END SUB
```

```
SUB HARDSPLIT
'**************************************************
'
'  Subroutine HARDSPLIT
'  Accepts material hardness range from programmer and
'  pertitions the hardness universe

  CLS
start
  midhard = 25
  PRINT "Insert metal hardness for the new material"
  PRINT
  PRINT "Type lowrange and then highrange in integer only"
  PRINT

  INPUT "lowrange=", lownum
  INPUT "highrange=", highnum

  IF lownum > highnum THEN
    CALL ERRORMESSAGE2
    GOTO start
  ELSE
    lowrange = lownum
    highrange = highnum
    lownum = lownum + midhard
    highnum = highnum - midhard

    FOR i = 0 TO 20
      hd(i) = (highnum - lownum) / 20 * i + lownum
    NEXT i
  END IF
END SUB

SUB HARDTABLE
'**************************************************
'
'  Subroutine HARDTABLE
'  Calculates membership values for each fuzzy sets of HARDNESS
'  and develops descritized universe of hardness shown in Table
'  5 2 in Chap 5
'
  LET a = 0
  LET b = 4
  LET c = 8
  LET d = 12
  LET e = 16
  LET f = 20
```

```
   FOR i = 0 TO 5
     IF i = 0 THEN
       FOR h = 0 TO 20
         IF h <= b THEN
VS           HARD(i, h) = (b - h) / (b - a)
         END IF
       NEXT h
     END IF
SOFT    IF i = 1 THEN
       FOR h = 0 TO 20
         IF (h = a) OR (h < b) THEN
           HARD(i, h) = (h - a) / (b - a)
         ELSEIF (h = b) OR (h <= c) THEN
           HARD(i, h) = (c - h) / (c - b)
         END IF

       NEXT h

     END IF
MED     IF i = 2 THEN
       FOR h = 0 TO 20
         IF (h >= b) AND (h <= c) THEN
           HARD(i, h) = (h - b) / (c - b)
         ELSEIF (h >= c) AND (h <= d) THEN
           HARD(i, h) = (d - h) / (d - c)
         END IF
       NEXT h
     END IF

MEDH     IF i = 3 THEN
       FOR h = 0 TO 20
         IF (h >= c) AND (h <= d) THEN
           HARD(i, h) = (h - c) / (d - c)
         ELSEIF (h >= d) AND (h <= e) THEN
           HARD(i, h) = (e - h) / (e - d)
         END IF
       NEXT h
     END IF

HA      IF i = 4 THEN
       FOR h = 0 TO 20
         IF (h >= d) AND (h <= e) THEN
           HARD(i, h) = (h - d) / (e - d)
         ELSEIF (h >= e) AND (h <= f) THEN
           HARD(i, h) = (f - h) / (f - e)
         END IF
       NEXT h
     END IF
```

```
VH      IF i = 5 THEN
        FOR h = 0 TO 20
          IF (h >= e) AND (h <= f) THEN
            HARD(i, h) = (h - e) / (f - e)
          END IF
        NEXT h
      END IF
    NEXT i
    CLS
    PRINT "            Discretized universe of hardness is as follows             "
    PRINT "  ***************************************************                   "
    PRINT "  ***************************************************                   "

    FOR i = 0 TO 5
      FOR h = 0 TO 20
        PRINT HARD(i, h),
      NEXT h
      PRINT
    NEXT i
    PRINT
    PRINT
    PRINT
    CALL TESTING

  END SUB

  SUB MAIN MENU
'***************************************************
'
'  Subroutine MAIN MENU
'  Displays 3 options for the system administrator

     CLS
     PRINT "************************************************************"
     PRINT "* Welcome to the Fuzzy Expert System for tool selection        *"
     PRINT "*                                                              *"
     PRINT "************************************************************"

     PRINT "To insert a new cutting material type ------------------------ 1        "
     PRINT
     PRINT "To change a record detail type -------------------------------- 2        "
     PRINT
     PRINT "To exit from the system type ---------------------------------- 3        "
     PRINT
     PRINT "Please type integer number only                                          "
     PRINT
     INPUT choice                    'getting user's choice


  END SUB
```

```
SUB MAKEQUA
'************************************************************
'
'  Subroutine MAKEQUA
'  Estublishes the relationship between material hardness
'  and cutting speed in the form of an equation y=mx+c,
'  using least square method

    CLS
    LET n = 21
    LET m = 0
    LET c = 0
    LET x = 0
    LET y = 0
    LET z = 0
    LET xy = 0

    FOR i = 0 TO 20
      x = x + hd(i)                          'Holds all the sums of x

      z = z + (hd(i) * hd(i))                'Hold  all the sums of x^2

      y = y + ACULSPEED(i)                   'Holds all the sums of y

      xy = xy + (hd(i) * ACULSPEED(i))       'Holds all the sums of xy

    NEXT i


    m = ((y / n) - (xy / x)) / ((x / n) - (z / x))
    c = (y / n) - (m / n * x)

    cd mname = LCASE$(matname$)
    cd tname = LCASE$(toolname$)
    cd doct = doc
    cd hardlow = lowrange
    cd hardhigh = highrange
    cd equam = m
    cd equac = c
```

```
PRINT " material name *********   ", cd mname
PRINT
PRINT " toolname **************   ", cd tname
PRINT
PRINT " depth of cut **********   ", cd doct
PRINT
PRINT " material lowrange *****   ", cd hardlow
PRINT
PRINT " material highrange ****   ", cd hardhigh
PRINT
PRINT " m part of the equation    ", cd equam
PRINT
PRINT " c part of the equation    ", cd equac
PRINT
PRINT " Is it ok to save this record"
PRINT
PRINT " Please type Y/N"
INPUT ans$
IF (ans$ = "Y") OR (ans$ = "y") THEN
  R = LOF(1) / 94
  R = R + 1
  PUT #1, R, cd      'Writes the record to Tool dat
  CLS
  PRINT "I have just written one record in the file"
  PRINT
  CALL TESTING
END IF
number = lowrange
FOR k = 0 TO 20
  hd(k) = (m * number) + c
  number = (highrange - lowrange) / 20 + number
NEXT k
PRINT "Fuzzy cutting speeds for ****",            cd mname
PRINT
PRINT "Hardness low  range  ********",            cd hardlow
PRINT
PRINT "Hardness high range  ********",            cd hardhigh
PRINT
PRINT "For depth of cut(mm) ********",            cd doct
PRINT
PRINT "Using cutting tool   ********",            cd tname
PRINT
PRINT "      are as follows      "

FOR k = 0 TO 20
  PRINT hd(k),
NEXT k
PRINT
PRINT
CALL TESTING

END SUB
```

```
   SUB OPMENU
'*************************************************************
'
'  Subroutine OPMENU
'  Offers two types of materials that are available on
'  the system and accepts user's choice

     CLS

     PRINT "***************************************************************"
     PRINT "             Welcome to the fuzzy expert system for            "
     PRINT "             selecting cutting conditions of materials         "
     PRINT "***************************************************************"
     PRINT "This system only caters for 2 types of material                "
     PRINT "             at the moment                                     "
     PRINT
     PRINT "1  Medium carbon leaded steel(BHN)             125--425        "
     PRINT
     PRINT "2  Free machining carbon wrought (BHN)         225--425        "
     PRINT
     PRINT "To select MEDIUM CARBON LEADED STEEL                  type--1 "
     PRINT
     PRINT "To select FREE MACHINING CARBON WROUGHT               type--2 "
     PRINT
     PRINT "To end this session                                   type--3 "
     PRINT
     PRINT "You must enter integer number only                             "
     INPUT userchoice


END SUB

   SUB SPEEDSPLIT
'*************************************************************
'
'  Subroutine SPEEDSPLIT
'  Accepts cutting speed range for the new material and
'  pertitions the speed universe

     CLS
speedstart
     PRINT "Enter speed range for the new material                "
     PRINT
     PRINT "Type lowrange and then highrange in integer only      "
     PRINT
     PRINT "-----------------------------------------------       "
     PRINT

     INPUT "Lowrspeed=", speedlow
     INPUT "highspeed="; speedhigh
     highspeed = speedhigh
     lowspeed = speedlow
```

```
    IF speedlow > speedhigh THEN
      CALL ERRORMESSAGE
      GOTO speedstart
    ELSE
      FOR ctr = 0 TO 10
        SP(ctr) = (speedhigh - speedlow) / 10 * ctr + speedlow
      NEXT ctr

    END IF


  END SUB

  SUB SPEEDTABLE
'*************************************************************
'
'  Subroutine SPEEDTABLE
'  Calculates the membership values for each fuzzy sets
'  of output variables SPEED as descritized universe,
'  shown in Table 5 3 in Chap 5
  LET a1 = 0
  LET b1 = 2
  LET c1 = 4
  LET d1 = 6
  LET e1 = 8
  LET f1 = 10

  FOR i = 0 TO 5

    IF i = 0 THEN
      FOR k = 0 TO 10
        IF (k <= b1) THEN
VSLOW          SPEED(i, k) = (b1 - k) / (b1 - a1)
        END IF
      NEXT k
    END IF

SLOW   IF i = 1 THEN
      FOR k = 0 TO 10
        IF (k = a1) OR (k < b1) THEN
          SPEED(i, k) = (k - a1) / (b1 - a1)
        ELSEIF (k = b1) OR (k < c1) THEN
          SPEED(i, k) = (c1 - k) / (c1 - b1)

        END IF
      NEXT k
    END IF
```

```
MSLOW   IF i = 2 THEN
       FOR k = 0 TO 10
         IF (k >= b1) AND (k <= c1) THEN
           SPEED(i, k) = (k - b1) / (c1 - b1)
         ELSEIF (k >= c1) AND (k <= d1) THEN
              SPEED(i, k) = (d1 - k) / (d1 - c1)
         END IF
       NEXT k
     END IF

MDHI   IF i = 3 THEN
       FOR k = 0 TO 10
         IF (k >= c1) AND (k <= d1) THEN
           SPEED(i, k) = (k - c1) / (d1 - c1)
         ELSEIF (k >= d1) AND (k <= e1) THEN
              SPEED(i, k) = (e1 - k) / (e1 - d1)
         END IF
       NEXT k
     END IF

HIGH   IF i = 4 THEN
       FOR k = 0 TO 10
         IF (k >= d1) AND (k <= e1) THEN
           SPEED(i, k) = (k - d1) / (e1 - d1)
         ELSEIF (k >= e1) AND (k <= f1) THEN
              SPEED(i, k) = (f1 - k) / (f1 - e1)
         END IF
       NEXT k
     END IF
VHIGH   IF i = 5 THEN
       FOR k = 0 TO 10
         IF (k >= e1) OR (k = f1) THEN
           SPEED(i, k) = (k - e1) / (f1 - e1)
         END IF
       NEXT k
     END IF
   NEXT i
   CLS
   PRINT "      Discretized universe of cutting speed is as follows         "
   PRINT "******************************************************"
   PRINT
   FOR i = 0 TO 5
     FOR k = 0 TO 10
       PRINT SPEED(i, k),
     NEXT k
     PRINT
   NEXT i
   PRINT
   PRINT
   PRINT
   CALL TESTING
   END SUB
```

```
   SUB TESTING
'**************************************************************
'
'  Subroutine TESTING
'  It holds the screen until user presses "Q" to proceed
'
     PRINT "please press Q or q to proceed"
     PRINT
     DO
       quit$ = INKEY$
     LOOP UNTIL (quit$ = "Q") OR (quit$ = "q")

   END SUB

   SUB TRUTHTABLE
'**************************************************************
'
'  Subroutine TRUTHTABLE
'  Estublishes the final table as shown in Table 5 8 in
'  Chap 5 which is the combination of 6 rules,using
'  Table 5 2 and Table 5 3

     FOR i = 0 TO 5
       FOR j = 0 TO 20
         FOR k = 0 TO 10
           LET TEMP = 0

           IF HARD(i, j) < SPEED(5 - i, k) THEN
             TEMP = HARD(i, j)
           ELSE
             TEMP = SPEED(5 - i, k)
           END IF

           IF TEMP > FINALTABLE(j, k) THEN
             FINALTABLE(j, k) = TEMP
           END IF

         NEXT k
       NEXT j
     NEXT i
     CLS
     PRINT "              Here are the contents of the final table              "
     PRINT " ****************************************************"
     FOR j = 0 TO 20
       FOR k = 0 TO 10
         PRINT FINALTABLE(j, k),
       NEXT k
       PRINT
     NEXT j
     PRINT
     CALL TESTING
   END SUB
```

```
SUB USEDATA
'**********************************************************
'
'  Subroutine USEDATA
'
'  Calls 4 other subroutines to find the cutting parameters
'  requisted by the user

   GETHARD       'Accepts material hardness(BHN) from user

   GETTOOL       'Accepts tool name required by the user

   GETREQFINISH  'Accepts required surface finish from the user

   GETFILE       'Opens DATA file and performs all the
                 'calculations based on the data in hand
                 'such as tool type, depth of cut,
                 'material hardness(BHN) ect to find cutting speed
                 'and also prints the cutting parameters on screen
                 'for the metal cutting operation

END SUB

SUB USERMENU
'**********************************************************
'
'  Subroutine USERMENU
'  Calls OPMENU subroutine to display operator's menu
'  on the screen

  CLS
  DO
    OPMENU
    SELECT CASE userchoice
      CASE 1
        matname$ = "medium carbon leaded"
        CALL USEDATA
      CASE 2
        matname$ = "free machining carbon wrought"
        CALL USEDATA
      CASE 3
        CLS
        PRINT "**************************************************"
        PRINT "*   Thankyou for using fuzzy expert system        *"
        PRINT "*                   Goodbye                       *"
        PRINT "**************************************************"
      CASE ELSE
        ERRORMESSAGE2
        CALL TESTING
    END SELECT
  LOOP UNTIL (userchoice = 3)
END SUB
```