

High-Speed Impact Characterisation of the GAA Smart Sliotar: Understanding Coefficient of Restitution at High Speeds

Ian Kiernan ^{a*}, Nigel Kent ^a, Kieran Moran ^b, Dermot Brabazon ^a

^a *Sch. of Mechanical and Manufacturing Engineering, Dublin City University, Dublin 9, Ireland*

^b *Department of Sport Science and Nutrition, Maynooth University, Kildare, Ireland*

* Corresponding author, Sch. of Mechanical and Manufacturing Engineering, Dublin City University, Dublin 9, Ireland. Tel: +353 1 700 8213. *E-mail address:*

ian.kiernan4@mail.dcu.ie (I. Kiernan).

Abstract

Hurling, a traditional Irish sport, is a field sport played on a pitch measuring up to 145 x 90 meters, using a hurley, a wooden stick traditionally made from ash, and a sliotar. The sliotar, the ball used in the game of hurling, is composed of a polyurethane core wrapped in leather. This paper investigates the high-speed performance characteristics of several new smart sliotars compared with conventional sliotars. These new sliotars are proposed for licensing for use by senior intercounty squads. The objective of this work was to evaluate the mechanical performance of sliotars through high-speed impact testing, with a focus on hurley/sliotar interactions. In particular, the change in coefficient of restitution (COR) with increasing impact speed was evaluated for the sliotar as played in the sport, i.e., with leather covering intact. The COR was found to decrease with increasing impact speed, following a consistent second-order trend for compliant sliotars. This new understanding from the data has not only facilitated a comparative analysis with traditional sliotars and test methods but also contributes to a more comprehensive understanding of sliotar behaviour under match-representative conditions than previously available.

Keywords: Hurling, Smart sliotar, Hurley, Impact testing, Coefficient of restitution, Sports engineering, Ball performance

Statements and Declarations

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1. Introduction

In the Irish national sport of hurling, a ball called a sliotar is struck with a traditional wooden stick called a hurley to move it up the pitch and through the goalposts to score. Historically, sliotars were unregulated and traditionally made from horsehair and covered in leather in the late 1800s. They began using a cork core in the early 1900s [1,2]. The Gaelic Athletic Association (GAA), which governs the sport, began regulating the sliotar after its inception in 1884, but until modern times, there was variation in the sliotar used.

The current sliotars used in the sport of hurling have moved away from cork or cork/synthetic cores to full synthetic cores made with polyurethane. The consistency of sliotars over the years has been called into question anecdotally by both fans and players. This concern led the GAA in 2024 to introduce the “Smart Sliotar”, a polyurethane core containing a chip (RFID tag) embedded in the core and surrounded by fluorescent yellow chrome synthetic leather [3], to ensure all sliotars used in competition perform similarly. This polyurethane core is manufactured using the foam moulding process. This process adds a blowing agent to the polyurethane, which, when injected into the mould, releases a gas, usually carbon dioxide or nitrogen, to achieve a lower density than a solid polyurethane ball [4,5].

The GAA updated its regulations for approved sliotars in 2022, as outlined in Section 4.4, Part 2 of the GAA Official Guide [6]. The regulations include diameter, mass, rim height, width, and leather thickness. In conjunction with these regulations, there is a specification for the coefficient of restitution (COR) of 0.522 - 0.576 for the sliotar, measured at a low-speed impact velocity of 5.94 m/s, equivalent to a 1.8-m drop test. This specification was brought in for standardisation, to ensure different brands of sliotars do not travel further than others,

giving a performance advantage. The COR is a constant measured as the ratio of the ball's velocity after hitting an object to the velocity before hitting the object [7, 8, 4]. For perfectly elastic bodies, the velocity before impact equals the velocity after impact, giving a coefficient of restitution of 1. For perfectly inelastic bodies, the velocity after impact will be zero, with a coefficient of restitution of 0.

We see other sports suffer from the same anecdotal evidence regarding different balls potentially having the capacity to travel farther from the study of Nathan et al. [9] where baseballs from the 1970s were tested vs balls from 2004 due to the belief that modern balls were “juiced”, i.e., livelier. The conclusion that there was no significant difference in COR between past and present disproved the anecdotal evidence, but there was evidence that the uniformity of balls from 2004 was better than that of the 1970s, which perhaps pointed to better quality control during the manufacturing process in modern balls.

The current official method for testing the COR for sliotars is conducted at Dublin City University (DCU) and is as described in Section 2: Experimental Methods. The impact speed of the sliotar in this drop test is 5.94 m/s and is considered to be low speed. There are two main methods for calculating the COR of balls used in sports. In tennis [10], cricket [11], hockey [12], and croquet, they use the standard drop test like hurling and only vary the drop height. Whereas in baseball [13] and lacrosse, they use an impact test where the ball is fired at high speed to calculate the COR of the ball. COR is specified in regulations for many ball sports, as shown in the table below, along with the measurement method.

Table 1: Regulatory coefficient of restitution values for major sports balls [4, 10-13]

Ball type	COR	Methodology
Hurling sliotar	0.522 – 0.576	1.8 m drop test
Tennis	0.73 – 0.76	2.54 m drop test
Cricket	0.53 – 0.62*	2 m drop test
Hockey	0.5 – 0.61*	2 m drop test
Croquet	0.76 – 0.86	2 m drop test
MLB Baseball	0.514 – 0.578	26.8 m/s impact
Lacrosse	0.6 – 0.7	26.8 m/s impact

*Approximate values for impacts with relatively rigid surfaces; COR may be substantially lower when the ball impacts a compliant surface.

Several studies on high-speed impact characterisation of sliotars were completed to compare the dynamic behaviour of the traditional sliotar cores, of cork surrounded by yarn winding, and the first generation of polymer foam cores from the early 2000s [4,14-16]. These studies analysed the cores by looking at the strain rate dependency of the two types of sliotars and also by calculating the COR by impact of the cores on a rigid plate at increased speeds up to 25 m/s. While these foundational studies established the impact characteristics of early sliotar designs, the dynamic behaviour of the modern polyurethane core sliotars remains unassessed at these higher velocities.

In a previous study of baseballs, which have a cork and rubber core, at higher speeds of 90 and 120 mph (40.2 and 53.4 m/s), the spread in values almost doubled ball-to-ball, and the COR decreased linearly with speed [9]. This trend was also noted by Collins et al. (2011) in their study of both cork and polymer core sliotars [14].

In addition, the previous studies by Collins et al. [4,14,15] and Hanley et al. [16] have all examined the COR by analyzing only the core of the sliotar, stripped of its leather covering. This removal of the cover was likely due to testing difficulty, as the outer covering has a large rib where the two leather panels are sewn together to cover the core. This ribbing would have made it difficult to measure center-of-mass (COM) displacement when using a software algorithm to calculate it from the high-speed video recording. Therefore, a critical research gap remains regarding the high-speed dynamics of the sliotar under actual playing conditions.

To address this gap, the sliotars used in this study are the new smart sliotars with polyurethane cores, which have not previously been scientifically tested at high speeds. The primary purpose of this study is to analyse the COR of these new smart sliotars from several manufacturers at speeds of up to 25 m/s, and to analyse if these results deviate from the official COR measured using the official drop test method. Further, while prior studies were restricted to using bare cores due to optical tracking difficulties caused by the leather outer covering's ribbing, this study assesses the fully assembled leather-bound sliotar in its as-played condition. By comparing these results with bare-core testing, this work aims to isolate and quantify the functional impact of the chrome leather covering on the sliotar's overall COR.

2. Experimental Methods

2.1 Sliotar Specifications and Physical Measurements

The sliotars utilised in this study were selected from a batch that had been previously tested and verified by the official GAA testing personnel in DCU to meet all dimensional regulations, i.e., diameter, rim height, rim width, and leather thickness, outlined in the “GAA Official Guide Part 2 – Rule 4.4 (i)” [6]. Therefore, for the specific scope of this experimental study, only the mass of the sliotar was explicitly measured and analysed. The regulations state that the mass of the sliotar shall be between 110 and 116 grams. There is also a regulation for the COR for a compliant sliotar, which must fall between 0.522 and 0.576 when subjected to the standard low-speed drop test. To verify the mass for compliance, a systematic weighing process was conducted. The total mass of each sliotar was initially measured using a precision digital laboratory scale (Sartorius Entris II). After completing the full set of impact tests, the synthetic coverings were carefully stripped from the polyurethane cores. The individual weights of the separated leather and bare cores were then measured using the same scale to analyse the components and their potential influence on the impact dynamics.

2.2 Coefficient of Restitution Calculations

The CORs of the various sliotar samples were assessed in this study. It is defined by the formula:

$$e = \frac{v_2 - v_1}{u_1 - u_2} \quad (1)$$

where, e is the COR, v_1 and v_2 are the rebound velocities of body 1 and 2 (velocity of separation), respectively, and u_1 and u_2 are the incident velocities of body 1 and body 2 (velocity of approach), respectively.

As we are dealing with a rigid body impact, i.e., the surface the ball is striking is not moving, we can simplify Eq. 1 to be:

$$e = \frac{v}{u} \quad (2)$$

For calculation of the COR in the drop test, Eq. 2 can be modified to use the rebound height as opposed to the velocities, as in Eq. 3:

$$e = \sqrt{\frac{h_2}{h_1}} \quad (3)$$

where h_1 is the initial height, and h_2 is the rebound height.

The rebound height can be calculated based on the time between bounces by changing the formula for the time of a freefall:

$$t = \sqrt{\frac{2h}{g}} \quad (4)$$

Solve for h_2 , rebound height:

$$h_2 = \frac{1}{2}gt_{fall}^2 \quad (5)$$

where, g is gravity (9.8 m/s^2), t_{fall} is the time for the ball to fall from the rebound height h_2 (i.e., total time between bounces divided by 2).

2.3 Impact Testing Protocols

Two experimental test methods were used in this project. One to calculate the drop test COR of a sliotar, and a second to calculate the high-speed COR of a sliotar.

The drop-testing method, as currently implemented in the official GAA testing, is used to calculate the COR of a sliotar and is also used in many ball sports worldwide [4]. This test involves dropping the ball from a height of 1.8 m onto a rigidly mounted solid plate to measure the time between bounces. To ensure the characterisation remained an isolated measure of ball dynamics, a rigid steel target was employed in accordance with the principles of wave propagation established by Goldsmith [17]. By utilising a target with mechanical stiffness and mass significantly greater than that of the sliotar, the collision approximates an impact against an infinitely rigid immovable wall. This target configuration prevents the target from moving, thereby mitigating any kinetic energy loss that would otherwise occur through macroscopic deformation or vibrational excitation of the apparatus. Consequently, the energy dissipated during the collision is confined almost entirely to the viscoelastic compression and recovery of the sliotar itself, ensuring that the resulting COR accurately reflects only the material characteristics of the test samples.

In this test, each sliotar is released from a drop height of exactly 1.8 m, measured from the rigid impact surface to the lowest point of the sliotar prior to release, onto a metal plate mounted on top of the force plate (AMTI BMS600900 Series, 600 mm x 900 mm); a layout of this setup is shown in Fig. 1. A Vicon system (Vicon Motion Systems Ltd, UK) was used to capture the data (2000 Hz). This system outputs the frame/subframe along with the force in the X/Y/Z axes to a file format, which is converted to CSV. This data is then converted using a custom Visual Basic macro from frame/subframe & force data into time & force data, which then enables the calculation of the coefficient of restitution for each sliotar.

Nine sliotars were selected from nine different manufacturers. The testing was completed for all nine sliotars using both the full sliotar and just the core of the sliotar with the leather outer covering removed, Fig. 2. Each sliotar was dropped five times, with a valid drop counted

when the sliotar struck the centre of the plate on the initial drop and again when it fell back onto the plate.

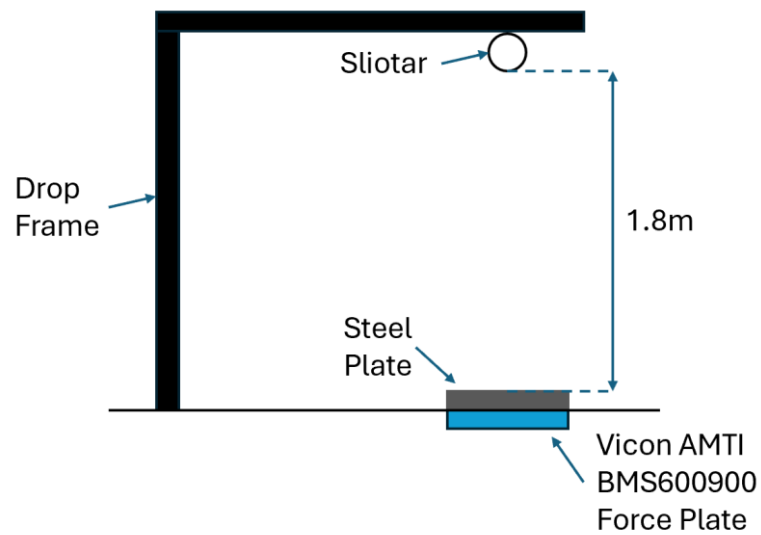


Fig. 1: Schematic of the official drop-test layout for measuring COR of the sliotar.



Fig. 2: Picture showing the test sliotars with marked sample numbers 401-409 and the same sliotars showing the core with leather covering removed.

The high-speed testing was performed on a “Sliotar Projectile Rig” designed by Dr. Fiachra Collins during his PhD thesis entitled “Parametric Impact Characterisation of a Solid Sports Ball, with a view to developing a standard core for the GAA sliotar” [4]. The rig was manufactured in-house within the School of Mechanical and Manufacturing Engineering, DCU. It consists of an 8-bar Ferrua SistemBlock air compressor connected to a pneumatic projection system comprised of a pneumatic actuator (SMC Pneumatics C95SDB63-500) with an internal bore of 63 mm, a stroke of 500 mm, G1 ports (dia. 25.4 mm), and a polymer piston. This piston allows for controlled, repeatable high-speed impacts, up to and including 25 m/s for testing purposes. Fig. 3 shows the system layout.

The system is controlled using a custom-built LabVIEW (V8.5, National Instruments, UK) program on the rig PC. This program uses multiple virtual instrument (VI) programs to control the systems on the projectile rig, which enables the user to set projectile speed and ball parameters to fire the sliotar to strike a steel impact plate and rebound into the recovery area. A LabVIEW VI then analyses the footage from the high-speed camera (MC1302 Camera, Mikrotron GmbH, Germany), which calculates and outputs multiple parameters such as maximum deformation based on centre of mass, peak impact force, and COR. For the purpose of this paper, the parameters of interest are ‘Impact Velocity’ and ‘Coefficient of Restitution’. For review of valid data, ‘Approach’ and ‘Rebound Angle’ were also checked to verify the sliotar was fired on a perpendicular line to the impact plate. ‘Peak Force’ and ‘Contact Time’ were reviewed to ensure there were no speed miscalculations; i.e., a higher force or longer contact time would indicate an incorrect velocity reading.

For the high-speed testing, each sliotar was fired at speeds of 5, 10, 15, 20, and 25 m/s. Five valid results were collected for each sliotar at each speed. Data was also collected for the core only of the sliotars for a speed of 15 m/s. Five valid data points were collected for each core

at this speed. This latter data set was recorded to allow analysis of the effect of the leather covering on the sliotar in relation to COR.

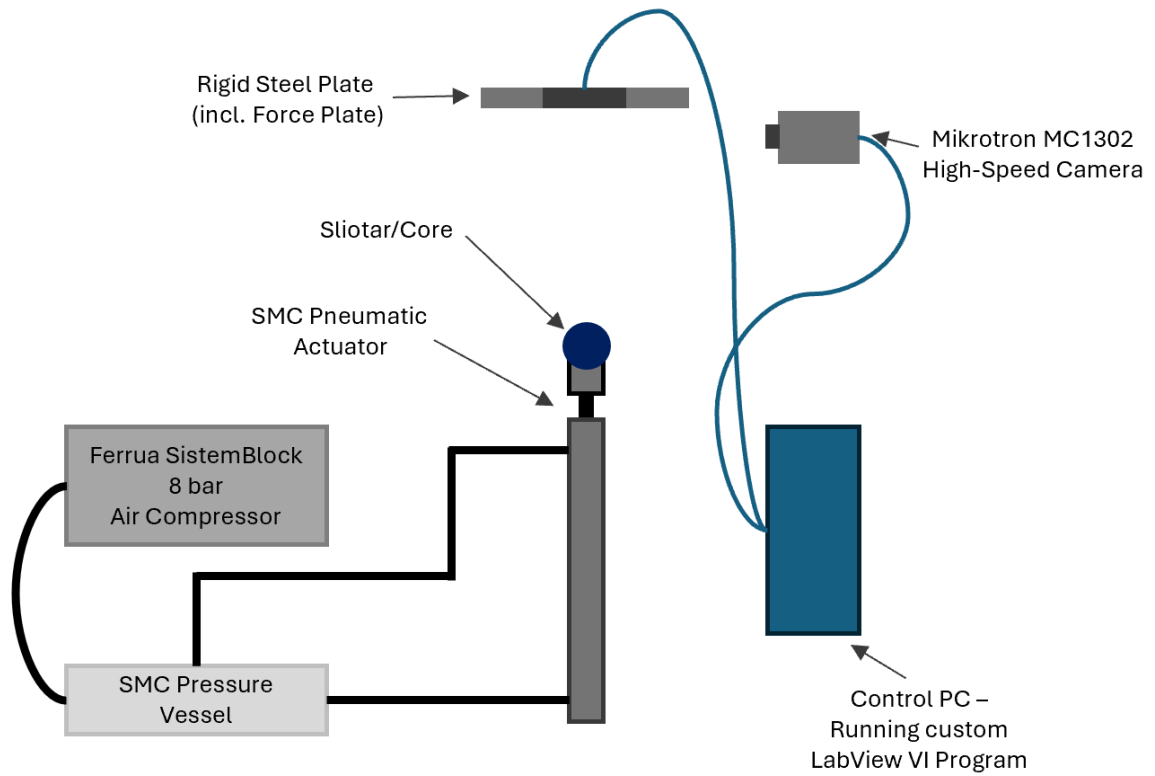


Fig. 3: Schematic of the slotted projectile rig layout.

2.4 Data Processing and Statistical Analysis

To calculate the COR across the different testing parameters, data was processed using two distinct systems: the first was the Vicon motion system, which was utilised for the regulation low-speed drop tests, and the second was the custom LabVIEW analysis program integrated with the sliotar projectile rig, which was used to evaluate the high-speed impacts from the 480 fps camera footage. Additionally, time-series data from the load cell was analysed via the LabVIEW program, with peak impact force and contact time calculated for each high-speed collision. For each sliotar at each test speed, five valid trials were averaged to establish the mean values.

Statistical analyses were performed using JMP software to evaluate the differences and relationships within the dataset. Paired t-tests were utilized to compare the COR of complete sliotars against their cores. Pearson correlation analyses were conducted to determine the relationship between sliotar weight and COR, as well as the correlation between bare core and full sliotar performance. A one-way analysis of variance (ANOVA) was performed to assess the effect of impact velocity on COR. Regression analyses were applied to the high-speed COR data. To justify selecting a second-order polynomial model over a standard linear regression for the overall population trend, the models were compared using the Adjusted R-squared metric. Statistical significance for all tests was established at a threshold of $p < 0.05$.

Results

3.1 Physical Characteristics

The total weight of the nine full sliotars ranged from 110.0 to 115.1 g, within the upper and lower limits (UL/LL), with a range of 5.1 g from lightest to heaviest. There are no regulations set for the weight of the components individually, but any significant differences in the weight of the leather covering would be of interest when reviewing the effect of the chrome leather on the COR. Fig. 4 shows differences in the weight of the leather coverings from sliotar to sliotar, with a maximum of 6.9 g, and in the weight of the core of 8.3 g. Notably, sliotars 405, 407, and 409 contained the three heaviest cores, which all exceeded 87.6 g, with sliotar 405 having the lightest leather covering at 23.8 g.

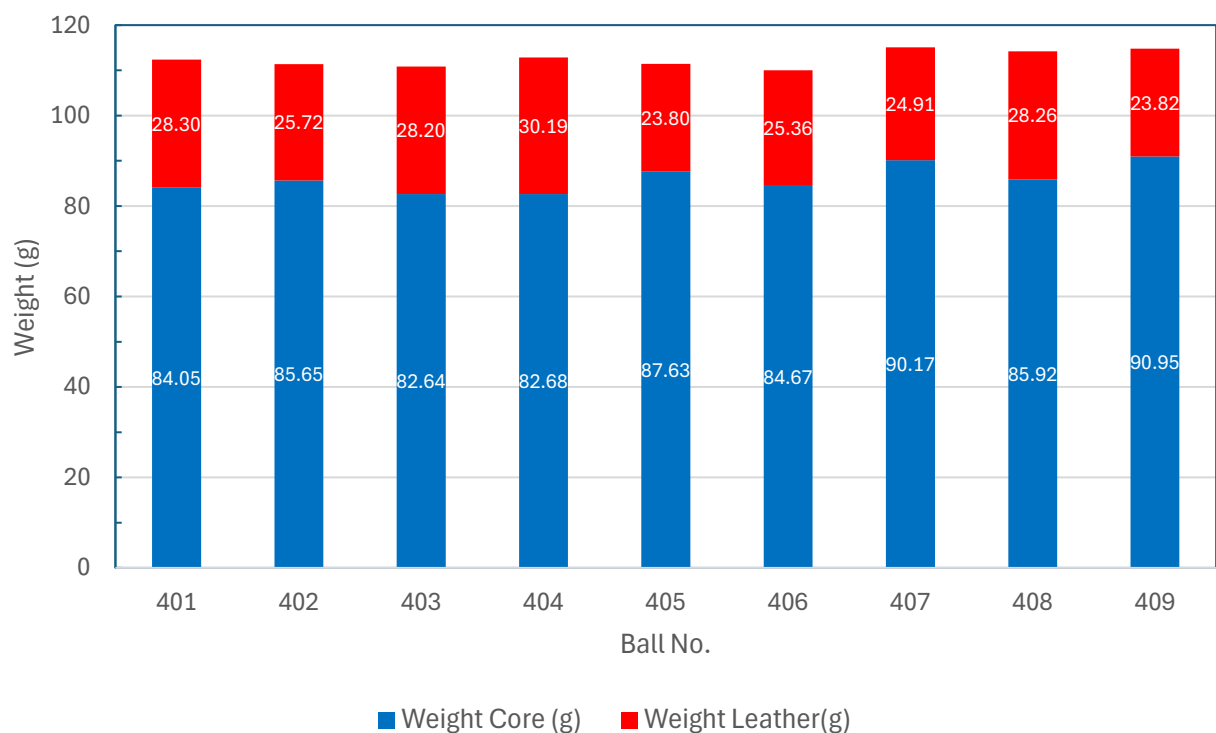


Fig. 4: Bar chart of sliotar weight, split into core and leather components.

3.2 Drop Test Results

For the official drop test, the CORs of full sliotars are shown in Fig. 5. This figure shows that six of the nine sliotars fell within the regulated COR range. Sliotars 401, 403, 404, and 406 are within similar ranges with means between 0.540 - 0.548. Sliotars 402 and 408 mean CORs were lower than these at 0.529 and 0.526, respectively. Sliotar 402 exhibited the largest drop-to-drop variation among the nine tested samples, with a maximum-to-minimum difference of 0.032. Sliotar 407 has the lowest COR in the slow-speed test with a mean of 0.509, falling 2.4% below the regulation's lower limit. Sliotars 405 and 409 had significantly higher CORs than the other seven. Sliotar 405 had a mean COR of 0.590 (2.4% above the upper limit), while 409 had a mean COR of 0.625 (8.5% above the upper limit). A Pearson correlation analysis confirmed there is no statistically significant correlation between the full sliotar COR and its total weight ($r = 0.091$, $p = 0.816$), core weight ($r = 0.462$, $p = 0.211$), or leather weight ($r = -0.537$, $p = 0.136$).

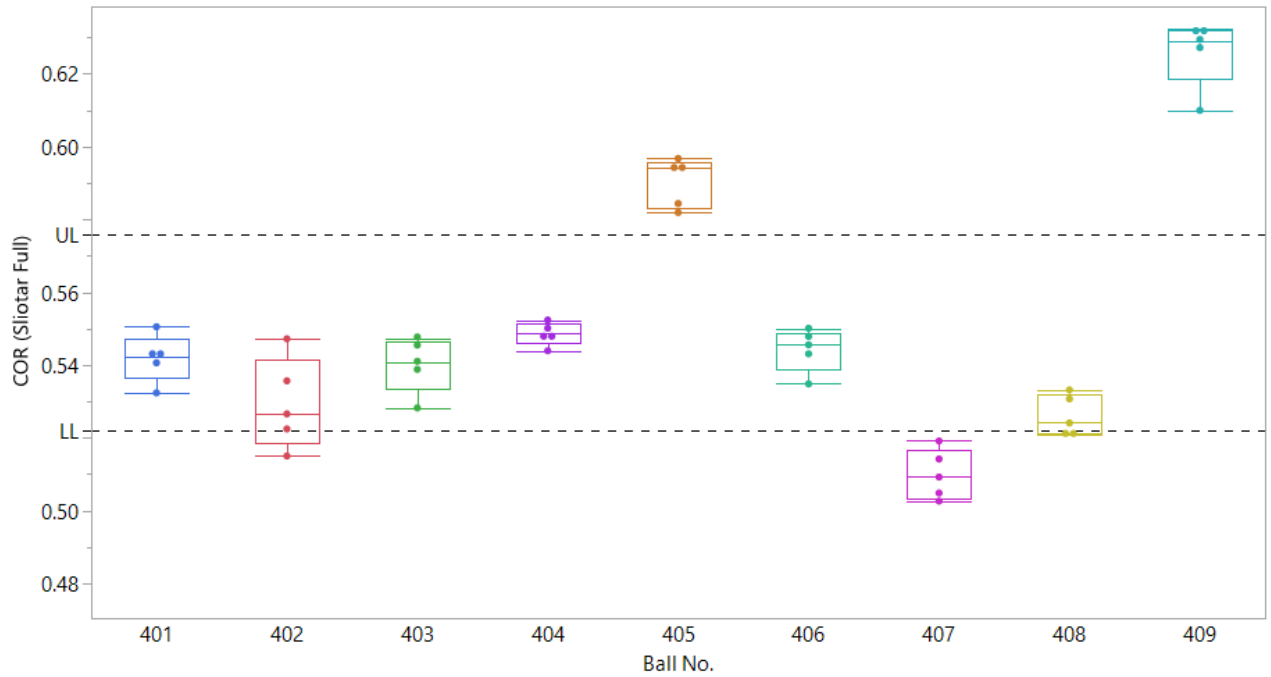


Fig. 5: Box plot of COR results for each full sliotar (with the leather covering intact) from the official drop test.

Fig. 6 shows the COR results from the drop test of the polyurethane sliotar cores alone. A paired t-test confirmed a statistically significant reduction in the coefficient of restitution when the leather covering was removed ($p < 0.0001$). The range of COR values recorded over the five drops for sliotars 401 and 404 was larger for the core than for the leather-wrapped core. For sliotars 402, 403, and 409, the range of values recorded was reduced by at least 50% in each case. Sliotars 405, 407, and 408 had very similar ranges between the full and core-only sliotar test. A Pearson correlation analysis revealed a highly significant positive correlation between the drop test COR of the bare polyurethane core and the drop test COR of the fully assembled, leather-wrapped sliotar ($r = 0.948$, $p = 0.0001$).

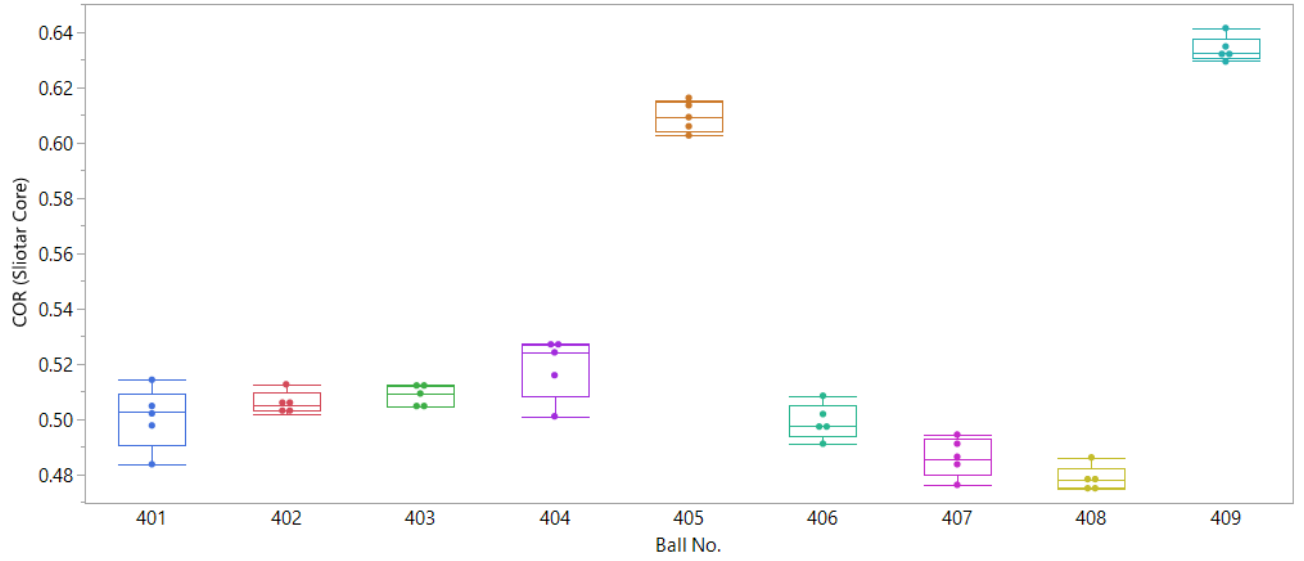


Fig. 6: Box plot of COR for each polyurethane sliotar core from the drop test.

3.3 High-Speed Results

For the high-speed results, the CORs for leather-bound sliotars 401 to 409 were measured across impact speeds from 5 to 25 m/s, and the results are shown in Fig. 7. To validate this observed velocity dependence statistically, a one-way ANOVA was conducted. The analysis confirmed that varying the impact speed has a highly significant main effect on the COR of the tested sliotars ($F(4, 259) = 118.59$, $p < 0.0001$). The results were fit with a second-order trendline, which shows a coefficient of determination $R^2 > 0.93$ for all sliotars. Two sliotars show visibly different COR trends: sliotars 405 and 409. The compliant sliotars exhibited a pronounced second-order curve, while the data for sliotar 405 demonstrated a nearly constant rate of COR reduction, resulting in a linear trend across all tested velocities from 5 to 25 m/s. The COR results for sliotar 409 were also close to a linear reduction for impact speeds from 5 to 20 m/s; however, the addition of the result at the higher speed of 25 m/s required a nonlinear trend fit. The quadratic model provided a marginally better fit across the tested sliotar population ($R^2_{\text{adj}} = 0.640$) compared to the linear model ($R^2_{\text{adj}} = 0.607$).

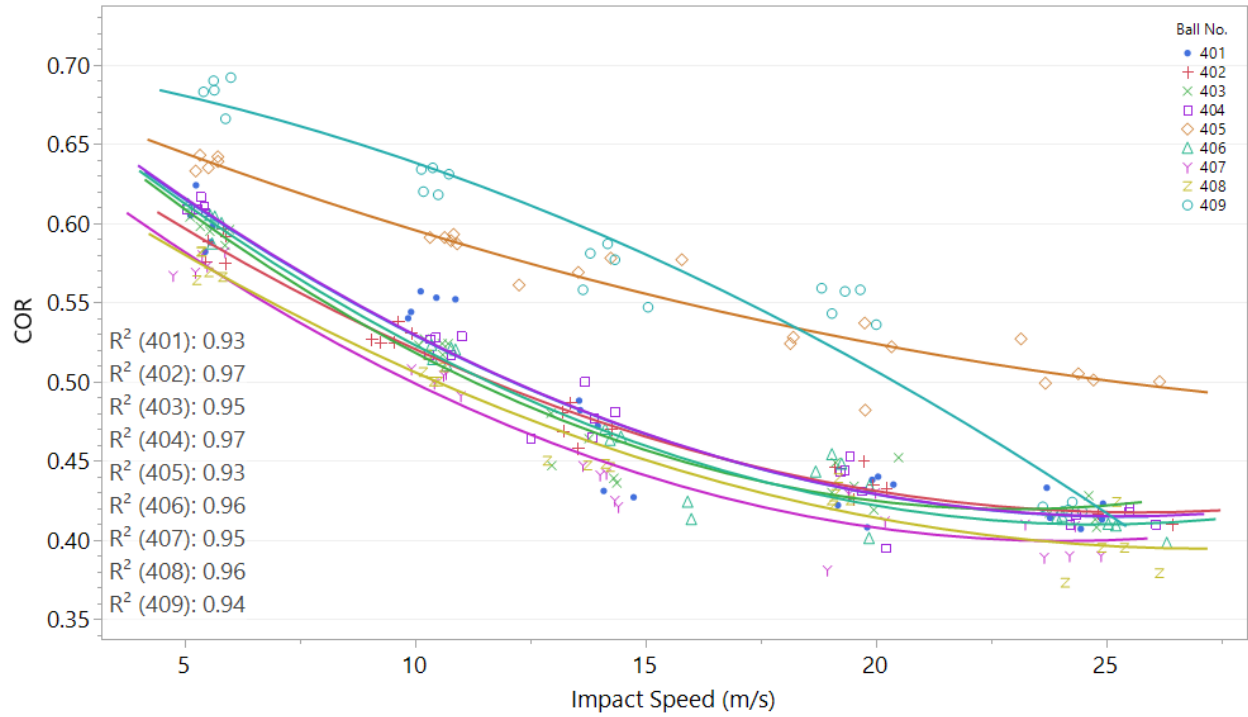


Fig. 7: COR vs impact speed for each sliotar test with quadratic fit and R^2 .

Load cell data from the high-speed testing provided dynamic physical metrics across the velocity intervals (Table 2). For the compliant sliotars, the mean peak force increased from 1.03 kN at 5 m/s to 4.99 kN at 25 m/s. Notably, the mean contact time exhibits a nonlinear trend decreasing from 2.55 ms at 5 m/s to a minimum of 2.12 ms at 15 m/s, before plateauing near 2.20 ms at increased velocities. The outlier, sliotar 409, exhibited significantly higher peak forces and shorter contact times than the compliant population.

Table 2: Summary of mean peak impact force and contact time for compliant sliotars across high-speed test intervals.

Impact Speed (m/s)	Mean Peak Force (kN)	Mean Contact Time (ms)
5	1.03	2.55

10	1.91	2.25
15	2.84	2.12
20	3.69	2.24
25	4.99	2.20

3.4 Comparison Between Drop Testing and High-Speed Testing

Fig. 8 shows the mean COR for each sliotar tested, comparing the full sliotar to the core from the official drop test and at an impact speed of 15 m/s. The difference in COR from full to core of the sliotars decreases as the impact speed increases, from the drop test (5.94 m/s) to 15 m/s impact speed, for all sliotars except 402 and 409.

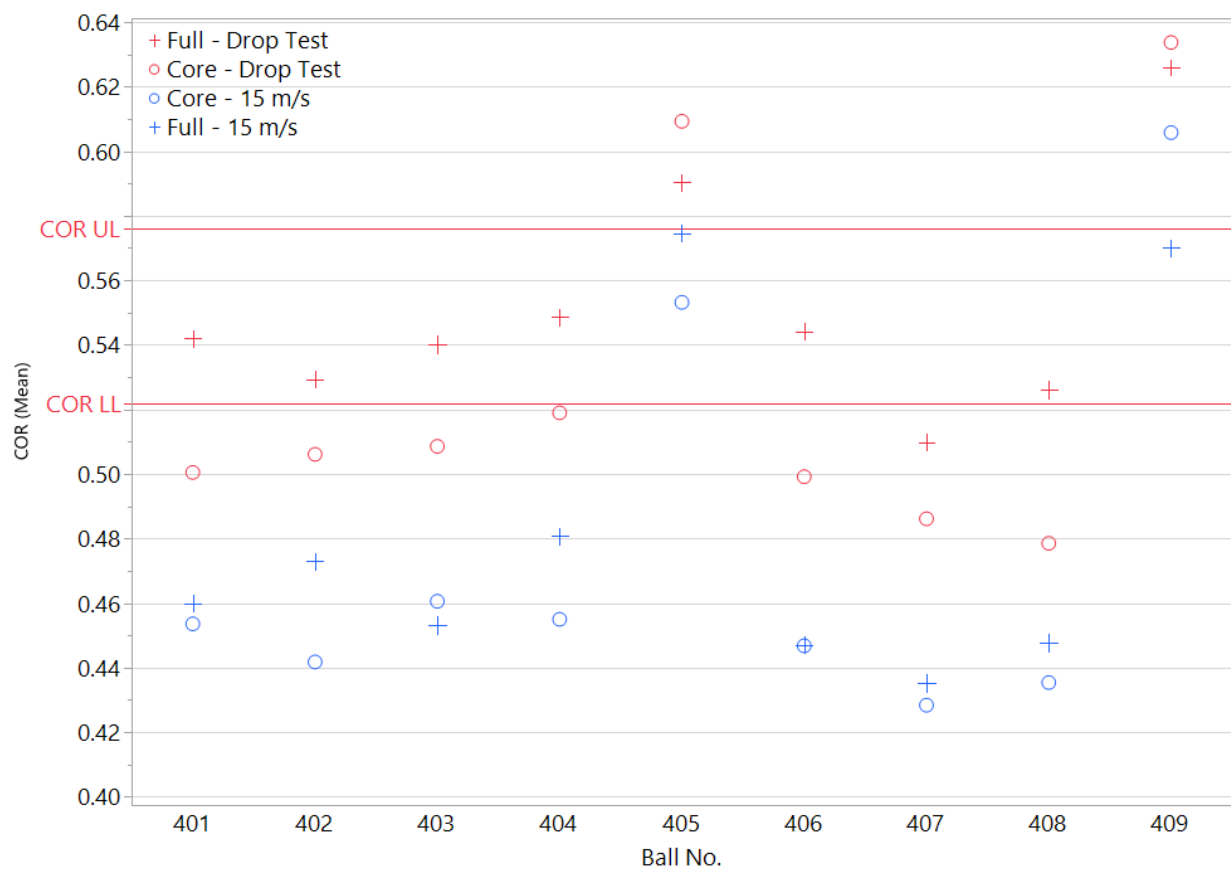


Fig. 8: COR (mean) of each sliotar for full sliotar and core only from official drop test and at 15 m/s. COR upper & lower limits are for full sliotar drop test only.

Fig. 9 shows the mean COR of each sliotar that met the official drop-test COR regulation for each speed from 5 m/s to 25 m/s. The drop-test box plot (5.94 m/s) is very similar to the highest high-speed box plot (25 m/s), with similar interquartile ranges (spread) and no significant outliers. The trend of reducing COR with increasing impact speed is also clearly visible.

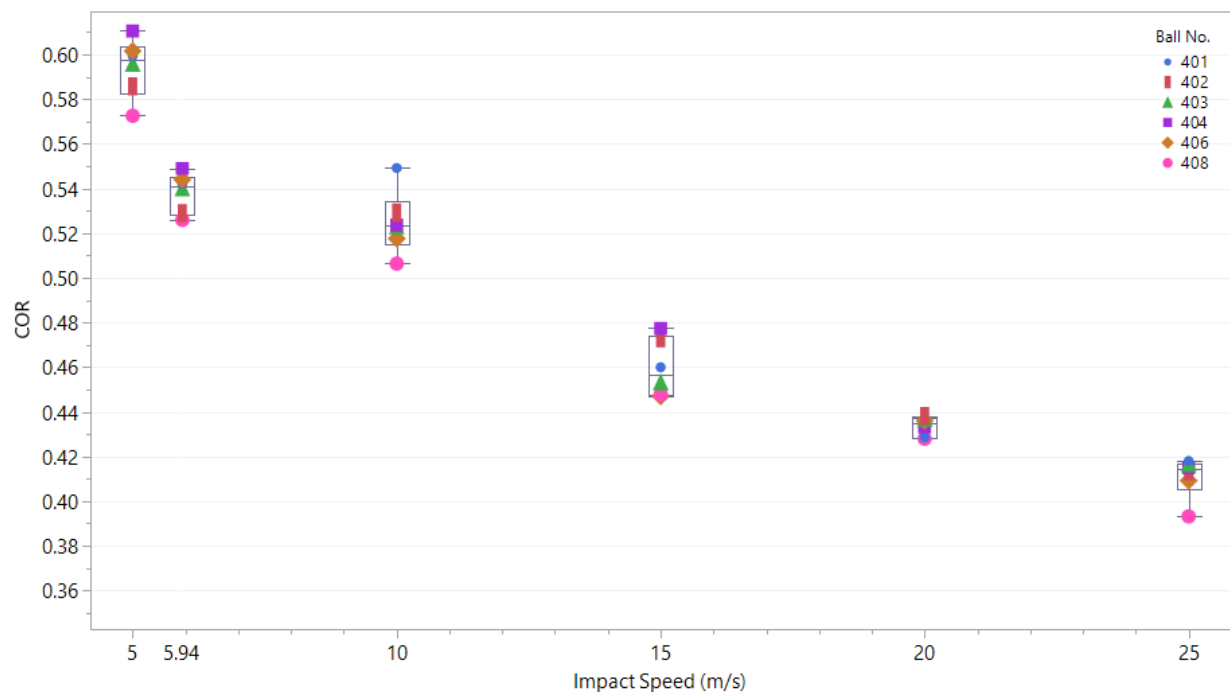


Fig. 9: Box plot of mean COR for each full sliotar from all speed tests and drop test.

4. Discussion

4.1 Physical Characteristics and Weight

Before testing for COR, the sliotars were measured (diameter, mass, rim height and width) to ensure they met the regulations set out in the GAA official guide. When testing for the official COR, the drop test was performed with the full sliotar. The previous studies which looked at sliotar characteristics [4,14-16] all tested the sliotar core only with the leather covering removed. In this study, the official drop test, the effect of impact speed, and the effects of leather wrapping were examined. To further allow comparison of leather-wrapped sliotar to the sliotar core, the high-speed COR test was also performed at 15 m/s impact speed to test these variants.

The cores of the modern compliant smart sliotars are lighter than the polymer cores characterised in earlier literature [4,15]. While previous studies often evaluated cores in the 95 g+ range, the compliant samples in this study featured significantly lighter cores (82.6 – 87.5 g). The correlation data confirms that heavier core variants, such as 405 and 409, return noncompliant, livelier COR values; the move toward lighter baseline cores likely reflects a deliberate manufacturing evolution. Manufacturers appear to be tuning the polyurethane density specifically to account for the change in weight and functional energy return provided by the chrome leather covering.

4.2 Mechanisms of the Drop Test

The functional role of the synthetic leather can be determined by comparing the bare core and the full sliotar during testing. It is seen that for seven of the nine sliotars the COR is higher with leather on than off. Leather is known to have good elastic properties and would deform under impact while returning to its original shape afterward; this elastic deformation is

hypothesized to mechanically help store the energy of impact and return it during collision, thereby improving the COR. Interestingly, when comparing the base COR of the smart sliotar cores evaluated in this study, the value appears to be lower than those of the early-generation polymer cores characterized by Collins et al. [4,14]. Collins reported core COR values exceeding 0.60 at low impact speeds; the compliant cores in this study exhibited a lower mean range of 0.49 - 0.54. This overall reduction in core liveliness also points to the deliberate manufacturing evolution mentioned in Section 4.1. From the study by Haron and Ismail [21], the cricket ball tested, which is a cork core surrounded by layered string and leather covering, had the lowest COR of the sports balls tested at 0.61. The authors found that the specific materials used in the ball, which are all “dissipative in nature,” result in the cricket ball having the low COR value. When we contrast this to the smart sliotar and consider the sliotars within the regulation range with the outer material of leather and inner material of a polyurethane core and an even lower COR of between 0.526 and 0.548, this suggests that modern polyurethane formulations are specifically engineered to be more dissipative than the traditional cork-based sports balls.

When comparing the drop test results for the full sliotar against the core only, it was noted that for seven of the full sliotars, the leather gave a consistent ~ 0.03 COR increase. This increase is not always the case for sports balls; Cross [18] demonstrated that surface coverings, such as the felt on a tennis ball, primarily contribute to energy loss through friction, whereas the chrome leather wrapper on the sliotar serves as an elastic energy-storage mechanism. Furthermore, despite the consistent elastic benefit provided by the leather covering, correlation analysis demonstrates that the underlying core dynamics overwhelmingly dictate the final performance of the sliotar. This strong statistical correlation indicates that manufacturing tolerances at the polyurethane foam moulding stage are a primary variable in overall sliotar compliance.

Sliotars 405 and 409 were both above the COR upper limit when tested with leather on and had an even higher COR value for the core only. These results show that the leather used on these sliotars does not perform the same as the seven others. This difference may be due to the synthetic core overriding the performance properties of the leather covering. Further investigation into the core material and the type of leather used in these two sliotars is needed to determine the cause of this reduction.

4.3 High-Speed Viscoelastic Dynamics

The nonlinear reduction in COR observed at higher impact velocities is consistent with the energetic models of viscoelastic dissipation proposed by Stronge [19]. According to Stronge, materials like high-density polyurethane, such as that used in the sliotar, exhibit velocity-dependent hysteresis in which energy loss to internal damping increases disproportionately with impact speed, justifying the use of a quadratic rather than linear regression. While the statistical improvement in fit for the quadratic model over the linear model is modest, it aligns with these theoretical expectations of viscoelastic energy dissipation at higher impact velocities. This nonlinear trend suggests that a quadratic model may better represent the compliant sliotars' velocity dependence.

To understand the mechanistic basis for this nonlinear reduction in COR at higher velocities, the impact force and contact time data acquired via the load cell were analysed. As impact velocity increased, the peak impact force scaled disproportionately while the contact time remained heavily constrained; this restricted contact time is consistent with dynamic strain-rate stiffening.

The nonlinear trend in contact time decreasing initially before plateauing at higher velocities reveals a two-phase mechanical response. The initial drop in contact time may be associated

with strain-rate stiffening, while the late-stage plateau suggests that at impact forces exceeding 3.5 kN, the time required for severe volumetric compression and the subsequent sluggish viscoelastic recovery may counteract further strain-rate stiffening. Based on established impact models [16, 19], as material undergoes higher-rate compression at elevated speeds, internal friction and viscoelastic dissipation are expected to increase exponentially. Consequently, this may indicate that the dynamically stiffer core loses a greater proportion of kinetic energy to internal damping rather than storing it elastically, which would serve as the primary mechanical driver for the observed reduction in COR.

The results differ slightly from previous studies by Collins et al. [4] and Nathan et al. [9], where a linear trend could be seen in COR vs impact speed. As stated previously, the tests in the prior studies listed were all performed on the core only, so we may be seeing the influence of the leather's elastic properties compared with the core-only results in those studies. From the test results, the rate of change of COR with increasing impact speed is more likely to diminish than to follow the linear trend seen in the named studies.

While Collins et al. [4] noted a COR drop off in bare cores, our results, for the six sliotars that pass the set regulations, provide a new learning that shows that the chrome leather covering acts to improve the COR, suggesting that the leather plays a more functional role in energy return than previously modelled. The observed reduction in COR with increasing velocity aligns with the findings of Arakawa et al. [20], who demonstrated for a solid polymer-based golf ball that the energy dissipation increases nonlinearly at higher impact forces (caused by higher speed). While Arakawa attributed this decrease in COR to the internal friction during high-ratio compression, our results suggest that, in the case of the sliotar, this nonlinear energy dissipation is further influenced by the elastic interaction of the chrome leather cover.

From the drop-test results, we know that sliotar 409 had the highest COR, which was outside of regulations. Sliotar 409 had an inverse second-order fit when compared to the other sliotars. The anomalously high COR performance of sliotar 409 is further elucidated by its load-cell data, which show higher peak forces and shorter contact times than the compliant population. This high COR may indicate an inherently stiffer material formulation that appears to undergo less viscoelastic damping, thereby returning a larger fraction of impact energy and resulting in a noncompliant ‘livelier’ sliotar.

4.4 Engineering Implications

The high-speed test for sliotar cores was performed at 15 m/s to analyze the difference in results between the leather-bound sliotar and sliotar core at this speed, as had been done with the drop test. For the majority of the nine sliotars, there is less of a difference between COR values for the full sliotar vs the core at 15 m/s when compared to the same results from the drop test. The data indicates that while the leather covering provides a consistent elastic benefit (mean COR increase by ~ 0.03), it does not alter the fundamental second-order relationship between velocity and COR. Testing of the leather-wrapped sliotar captures both the viscoelastic properties of the core and the functional energy return of the cover, thereby representing the complete mechanical system. Therefore, core-only testing is not required to characterize the high-speed performance, as the sliotar’s behaviour in its as-played state provides a highly reliable characterization of the internal core dynamics.

While the rigid steel plate used in this study provided a controlled environment for measuring the COR, it is important to note the findings of Haron and Ismail [21] regarding the target material. Their study of balls from various sports (golf, tennis, and cricket) highlighted that the mass and stiffness of the impact surface significantly govern the resulting COR. In real-

world play, the impact between the sliotar and an ash hurley, which is significantly less rigid than steel, would likely result in a higher total energy dissipation of the impact. Therefore, the COR values reported here represent the maximum potential energy return of the ball, providing a conservative benchmark for GAA performance standards.

4.5 Limitations and Future Work

This study successfully characterised the high-speed dynamics of fully assembled, leather-bound sliotars. However, several limitations should be noted.

First, the use of a rigid steel impact plate, while necessary to isolate the sliotars' independent material properties, does not fully replicate the mechanical impedance of an ash hurley, or hurleys of alternative materials. In real-world play, the flexibility of the hurley would likely result in greater total energy dissipation during the collision.

Second, a limitation of the optical tracking setup was the inability to accurately calculate dynamic lateral deformation for the fully assembled sliotars. The high-contrast black ribbing on the synthetic leather covering interfered with the tracking algorithm's edge-detection logic. Future iterations of this testing protocol should explore alternative deformation tracking methods, such as digital image correlation (DIC) or modified marker sets, to overcome the visual noise introduced by the sliotar's ribbing.

Finally, future research should expand these parameters to include the effects of environmental conditions, such as temperature and moisture absorption, on both the viscoelastic damping of the polyurethane core and the elastic response of the chrome leather.

5 Conclusion

This study evaluated the high-speed impact characteristics of fully assembled, leather-bound GAA smart sliotars at velocities up to 25 m/s. The results demonstrate that the coefficient of restitution for compliant full sliotars decreases nonlinearly as impact speed increases, following a statistically robust second-order trend. By testing the fully assembled ball, this study successfully isolated the functional role of the synthetic leather cover, which provides a consistent elastic energy return that increases the COR by an average of 0.03. Despite this contribution from the leather, correlation and load-cell data confirm that the underlying polyurethane core ultimately dictates the ball's performance. High-speed load-cell metrics suggest that as impact velocity increases, the core undergoes dynamic strain-rate stiffening, which drives the nonlinear reduction in COR.

From a regulatory perspective, a sufficiently tight range of COR values was recorded at each test speed for the compliant sliotars. Crucially, sliotars that met the regulatory COR range under the standard low-speed drop test maintained consistent performance at higher test speeds. These findings indicate that within the scope of the tested conditions, the standard low-speed drop test is generally sufficient to classify a sliotar's dynamic consistency. As such, the current standardised low-speed COR test remains an appropriate, resource-efficient baseline approach for assessing performance in line with regulatory requirements, allowing standards enforcers to ensure compliance without the requirement for routine high-speed data capture.

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