e-ISSN 2581-0405
Asian Journal of Applied Research for Community Development and Empowerment
Journal home page: http://ajarcde-safe-network.org ISSN 2581-0405

Development and Performance Validation of a Falling Weight Impact Tester for Coating Resistance Evaluation

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ARTICLE INFO

Article History:
RReceived: 06 July 2026
Final Revision: 17 July 2026
Accepted: 26 July 2026
Online Publication: 28 July 2026

KEYWORDS

Coating, Impact Coating, Falling Weight, ASTM D2794-93

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A B S T R A C T

This study presents the design, fabrication, and performance evaluation of a falling-weight impact testing apparatus for assessing the impact resistance of protective coatings in accordance with ASTM D2794-93: Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). The developed apparatus was designed to overcome limitations reported in previous studies, particularly regarding measurement accuracy, structural stability, and testing repeatability. The testing system was employed to evaluate the impact resistance of coated flat metallic specimens with a coating thickness of 900 ± 100 µm under controlled impact loading conditions. The experimental investigation examined the influence of two impact masses (1.8 kg and 3.6 kg) and three drop heights (0.50, 0.70, and 0.90 m), corresponding to different impact energy levels, on coating performance. The coating response was assessed by analyzing the occurrence and propagation of coating defects, particularly crack initiation after impact loading. The results demonstrate that the developed apparatus provides stable and consistent testing conditions while complying with the dimensional and operational requirements specified in ASTM D2794-93. Furthermore, variations in impact mass and drop height significantly influence the severity of coating damage, indicating that applied impact energy plays a critical role in determining coating resistance. The developed testing apparatus offers a reliable, accurate, and cost-effective alternative for laboratory-scale impact testing of protective coatings on metallic substrates and can support future research on coating performance evaluation and quality assurance.

Contribution to Sustainable Development Goals (SDGs):
SDG 8: Decent Work and Economic Growth
SDG 9: Industry, Innovation and Infrastructure
SDG 11: Sustainable Cities and Communities

1. INTRODUCTION

1.1. Research Background

Protective coatings are widely applied to metallic materials to enhance their resistance against environmental degradation, including corrosion, abrasion, and mechanical damage. The long-term performance of these coatings is strongly influenced by their ability to withstand sudden mechanical loading without cracking or delamination. Consequently, reliable evaluation of coating impact resistance is essential to ensure coating integrity and service life in demanding engineering applications, such as marine structures, offshore platforms, pipelines, bridges, and other industrial infrastructures.

Among the available mechanical characterization methods, the falling-weight impact test has become one of the most widely adopted techniques for assessing the resistance of organic coatings to rapid deformation. This method evaluates the ability of a coating system to absorb impact energy generated by a freely

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falling mass and determines the extent of coating failure, which is commonly characterized by crack initiation, fracture, or delamination after impact. Because the test reproduces localized dynamic loading conditions frequently encountered in practical service environments, it provides a realistic assessment of coating durability. Accordingly, the ASTM D2794-93 standard establishes detailed requirements for specimen support, indenter geometry, impact mass, and testing procedures to ensure the accuracy, repeatability, and comparability of experimental results [1].

Several previous studies have investigated the impact resistance of coated metallic substrates using falling-weight testing. Debrita (2017) evaluated ASTM A36 steel specimens using a constant impact mass of 500 g with drop heights ranging from 70 to 90 cm [2]. However, the testing apparatus did not fully comply with ASTM D2794-93, particularly regarding the indenter dimensions and the absence of a standardized specimen support (panel support), potentially affecting measurement reliability. Similarly, Budiarto et al. (2024) conducted impact testing on ASTM A36 steel using a constant impact mass of 600 g and drop heights between 50 and 100 cm. Although the study demonstrated the influence of impact energy on coating damage, the testing equipment again deviated from ASTM specifications, particularly in the indenter geometry and specimen support design [3]. Comparable limitations were also reported by Fakhri et al. (2024), who investigated coated SS400 steel using a 500 g impact mass with drop heights of 40 and 60 cm. The experimental setup likewise lacked compliance with ASTM D2794-93 due to non-standard indenter dimensions and the absence of an appropriate panel support [4]. Jia et al. reported that increasing epoxy coating thickness from 0.5 to 1.0 mm enhanced the coating's energy absorption capability under impact loading, demonstrating that thicker coatings dissipate a greater portion of the applied impact energy [11].

A critical review of these studies reveals a common limitation: the testing apparatuses were not fully designed in accordance with ASTM D2794-93. In particular, the absence of standardized specimen clamping systems, panel support, and compliant indenter geometry may introduce specimen movement during impact, reduce testing repeatability, and compromise the validity of the measured coating performance. Therefore, there remains a need to develop a standardized falling-weight impact testing apparatus capable of producing reliable, repeatable, and ASTM-compliant measurements for laboratory-scale coating evaluation.

To address these limitations, the present study develops and validates a falling-weight impact testing apparatus designed in accordance with the requirements of ASTM D2794-93, Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). The developed apparatus incorporates several key design improvements to enhance testing accuracy and repeatability. A 100 cm guide rail equipped with dual hardened steel shafts and precision bushings ensures smooth, vertically aligned movement of the falling weight, thereby minimizing lateral displacement during impact. The impact assembly consists of a 37 mm diameter impact body fitted with a 15.9 mm hemispherical indenter, fully complying with ASTM specifications. The specimen support includes a 16.3 mm central opening that provides standardized backing conditions during testing. In addition, a toggle clamp is incorporated to securely restrain the specimen and eliminate movement throughout the impact event, while an adjustable stopper mechanism enables accurate positioning of the impact mass at predetermined drop heights [1].

The developed apparatus was evaluated using two impact masses (1.8 kg and 3.6 kg) and three drop heights (0.50, 0.70, and 0.90 m) to investigate the influence of applied impact energy on coating performance. Coating resistance was assessed through visual examination of crack formation after impact. By integrating standardized mechanical components with improved specimen fixation and guidance systems, the proposed apparatus is expected to provide higher testing accuracy, better repeatability, and greater compliance with ASTM D2794-93 than previously reported laboratory-scale impact testing devices. The outcomes of this study contribute to the development of reliable coating evaluation equipment for both research laboratories and industrial quality assurance applications.

1.2. Literature Review

The impact coating test is a mechanical testing method used to evaluate the resistance of protective coatings to sudden impact loading or dynamic deformation. One of the most commonly used techniques is the falling-weight method, in which a weighted impactor is released from a predetermined height onto the coated surface to simulate impact conditions encountered during service.

During the test, the coated specimen is subjected to successive impacts. If no visible coating failure, such as cracking, is observed, the drop height is gradually increased until coating damage occurs. The impact resistance is then determined based on the maximum impact energy that the coating can withstand without failure.

The testing principle is based on the conversion of gravitational potential energy into impact energy. As the impactor falls freely, its potential energy is transformed into kinetic energy, which is transferred to the coating upon contact. Increasing the drop height results in higher impact energy and greater localized deformation, potentially causing coating defects such as cracks or delamination.

This method provides a practical and reliable assessment of coating durability under dynamic loading conditions and is widely used to evaluate the mechanical performance of protective coatings in industrial applications. The schematic illustration of the falling-weight impact test is presented in Figure 1.

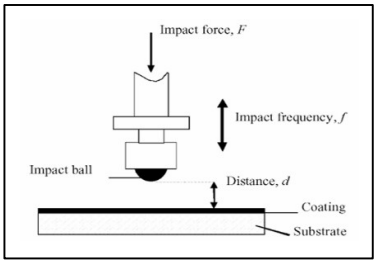

Fig. 1. Schematic Illustration of The Falling-Weight Impact Coating Test Mechanism [5]

Debrita (2017) investigated the impact resistance of an epoxy-coated ASTM A36 steel plate with a thickness of 10 mm and a dry film thickness (DFT) of 250 µm. The impact test was conducted using the falling-weight method with a constant impact

mass of 500 g and drop heights ranging from 70 to 90 cm. The experimental results showed that the coating remained intact without visible cracking throughout the tested impact conditions [2].

These findings indicate that the epoxy coating exhibited sufficient resistance to sudden impact loading within the investigated impact energy range, maintaining its structural integrity under dynamic loading. The study demonstrates the effectiveness of the coating in resisting crack initiation under moderate impact energies, although coating failure may occur at higher impact energy levels beyond the tested conditions. The experimental setup used in the study is illustrated in Figure 2.

Fig. 2. Impact Coating Falling Weight Test [2]

The falling-weight impact test for protective coatings is standardized in ASTM D2794-93, Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). This standard specifies the testing procedure for evaluating the resistance of organic coatings to localized impact loading produced by a freely falling weight. The primary objective of the test is to determine the ability of a coating to withstand rapid deformation without cracking or other visible forms of failure [1].

In this method, the coated specimen is positioned on a rigid support, and a hemispherical indenter is impacted onto the coated surface by releasing a weighted mass from a predetermined height. After each impact, the coating is visually inspected for damage, such as cracking or delamination. If no failure is observed, the drop height is gradually increased until coating failure occurs. The maximum impact energy sustained without visible damage is used as an indicator of the coating's impact resistance.

The ASTM D2794-93 apparatus consists of three principal components that ensure accurate, repeatable, and standardized testing.

1. Indenter

The indenter is the primary impact component that directly transfers impact energy to the coated specimen. According to ASTM D2794-93, the indenter consists of a hardened steel punch with a hemispherical tip having a diameter of either 12.7 mm (0.500 in.) or 15.9 mm (0.625 in.). During testing, the indenter is aligned vertically above the specimen to ensure that the impact load is applied precisely to the desired location, thereby simulating localized mechanical deformation under service conditions.

2. Guide Tube

The guide tube is a vertical column that directs the falling impact mass, ensuring smooth and accurate movement during testing. ASTM D2794-93 specifies a guide tube length ranging from 0.6 to 1.2 m (24–48 in.). The guide tube is mounted on the base frame and incorporates a longitudinal slot that allows the impact mass to be positioned and released from predetermined heights. This configuration minimizes lateral movement during free fall and improves the repeatability and accuracy of the impact test.

3. Panel Support

The coated specimen is placed on a rigid steel panel support during testing. The support contains a 16.3 mm (0.64 in.) diameter central opening located directly beneath the indenter, as specified by ASTM D2794-93. This opening provides appropriate support while allowing localized deformation of the substrate during impact. A properly designed panel support ensures specimen stability throughout the test and contributes to the consistency and reliability of the measured coating performance.

During the falling-weight impact test, protective coatings may fail due to the high localized stresses generated by impact loading. The most common forms of failure are cracking and indentation (dent formation), both of which reflect the coating's inability to absorb impact energy without sustaining mechanical damage. The primary objective of the test is to identify the onset and type of coating failure, particularly crack formation, which serves as a key indicator of coating integrity.

Cracking is considered one of the most critical failure modes because it compromises the protective function of the coating and facilitates the penetration of moisture, oxygen, and corrosive species to the underlying metallic substrate. Cracks develop when the stresses induced by impact exceed the coating's deformation capacity, resulting in fracture within the coating layer or at the coating–substrate interface.

Previous studies have demonstrated various crack formation mechanisms under impact loading. Wang et al. (2021) reported that impact loading can initiate crack formation in protective coatings [6]. Zhang et al. (2020) observed that microcracks tend to nucleate and propagate around particles or microstructural heterogeneities within the coating [7]. Furthermore, Chen et al. (2023) identified characteristic ring cracks and radial cracks as dominant failure patterns associated with high-impact loading, indicating progressive coating degradation [8]. Representative examples of these crack morphologies are presented in Figures 3**.**

An indentation (dent) is a localized permanent deformation produced by falling-weight impact loading and is not necessarily considered a coating failure. The presence of a dent indicates that the coating has undergone plastic deformation while still maintaining its structural continuity and protective function. Unlike cracking, indentation does not create a direct pathway for corrosive media to reach the metallic substrate, provided that the coating remains intact.

https://doi.org/10.29165/ajarcde.v10i3.1188

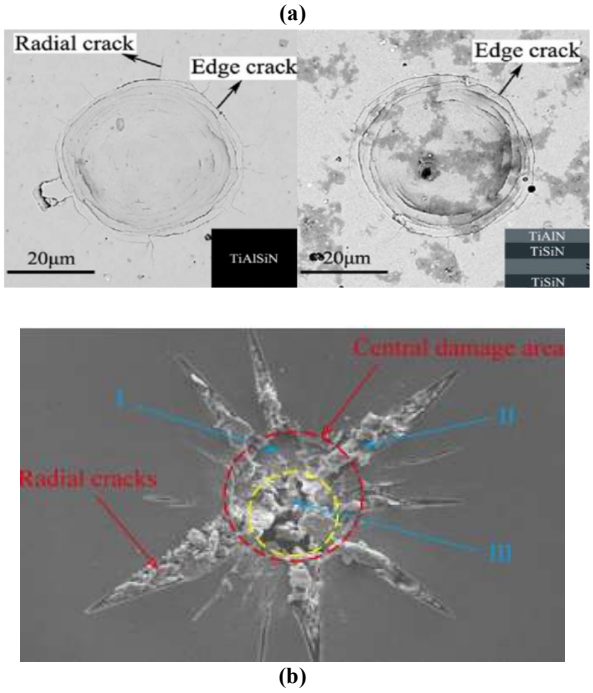

Fig. 3. (a) Crack in Coating After Impact Falling Weight [6] (b) Radial Crack in Coating After Impact Falling Weight [8]

According to Wang et al. (2008), the impact damage mechanism in coating systems is governed by the distribution of Hertzian contact stresses generated during loading. Initially, the concentrated compressive stress beneath the indenter produces localized deformation, whereas tensile stresses that develop around the contact perimeter initiate ring cracks once the coating fracture strength is exceeded. As the impact energy increases, these cracks propagate radially due to stress redistribution and elastic recovery during unloading, leading to crack coalescence, delamination, and eventually coating spalling. Therefore, the evolution of impact damage generally follows the sequence of localized deformation, ring crack initiation, radial crack propagation, and coating failure through spalling [10].

Budiarto et al. (2024) reported that epoxy-coated specimens subjected to increasing impact heights exhibited progressive dent formation without visible cracking. These findings suggest that the coating was capable of absorbing the applied impact energy through localized deformation while preserving its mechanical integrity [3]. Therefore, dent formation may represent a non-catastrophic response to impact loading and can be regarded as an indicator of the coating's energy absorption capability rather than coating failure. A representative example of impact-induced indentation is shown in Figure 4.

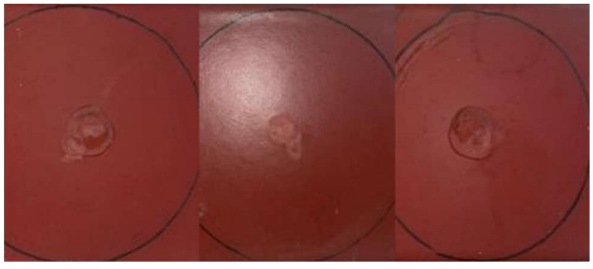

Fig. 4. Dent in Coating After Impact Falling Weight [3]

The inspection of coating failure following the falling-weight impact test was performed in accordance with ASTM D2794-93, Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). The standard recommends several inspection methods to detect coating damage, particularly crack initiation that may not be visible during visual examination. The principal inspection methods are described as follows.

1. Magnifying Loupe Inspection

A magnifying loupe is used to examine the impacted area for visible signs of coating damage. Magnified visual inspection enables the detection of fine surface cracks and other minor defects that cannot be readily identified with the naked eye, thereby improving the accuracy of crack assessment.

2. Copper Sulfate Test

In this method, a flannel cloth saturated with an acidified copper sulfate ($CuSO_4$) solution is placed over the impacted area for approximately 15 minutes. After removal, the surface is examined for copper deposition or rust staining. The presence of either indicates that the coating has fractured, exposing the metallic substrate and allowing electrochemical reactions to occur.

3. Wet Sponge Holiday Detector

A wet sponge holiday detector is employed to identify fine cracks or discontinuities in the coating that may not be visible by optical inspection. During testing, the detector is electrically connected to the metallic substrate while a wetted sponge electrode is moved across the impacted area. If a crack or coating discontinuity exposes the substrate, an electrical circuit is completed, triggering an audible or visual alarm. This method provides a rapid and sensitive means of detecting coating defects following impact testing [1].

2. MATERIALS AND METHODS

This study focuses on evaluating the impact resistance of protective coatings under falling-weight loading and investigating the failure mechanisms induced by impact. The primary objective is to design, fabricate, and validate a falling-weight impact testing apparatus that complies with ASTM D2794-93, Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). In addition, the study examines the influence of key testing parameters, including impact mass and drop height, on the impact resistance and failure behavior of coated metallic specimens.

The impact resistance of the coating is evaluated by determining the maximum applied impact energy that can be sustained before the onset of coating failure, particularly crack initiation. This parameter represents the coating's ability to absorb impact energy while maintaining its structural integrity. The mean failure energy (MFE) is calculated based on the procedure described in ASTM D5420-04, Standard Test Method for Impact Resistance of Flat, Rigid Plastic Specimen by Means of a Striker

Impacted by Falling Weight (Gardner Impact). The failure energy is determined from the applied impact mass and drop height according to the following equation:

$$MFE = h .w .f$$

where:

MFE = mean failure energy (J),
(h) = drop height (mm),
(w) = impact mass (kg), and
(f) = conversion factor to Joules

The calculated MFE represents the applied impact energy required to initiate coating failure and serves as a quantitative parameter for comparing the impact resistance of coatings under different testing conditions. Higher MFE values indicate greater energy absorption capability and improved resistance to impact-induced cracking [9].

3. RESULT AND DISCUSSION

3.1. Design and Development of the Falling-Weight Impact Testing Apparatus

The falling-weight impact testing apparatus was designed and developed in accordance with the requirements specified in ASTM D2794-93, Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). The three-dimensional model of the apparatus was created using Autodesk Inventor to ensure dimensional accuracy and compliance with the standard.

The developed apparatus was designed to apply controlled impact loading to coated steel specimens using interchangeable impact masses of 1.8 kg and 3.6 kg. The impact energy was varied by adjusting the drop height from 100 mm to 1000 mm (10–100 cm), enabling the evaluation of coating performance under different impact energy levels. The overall design of the developed falling-weight impact tester is presented in Figure 5.

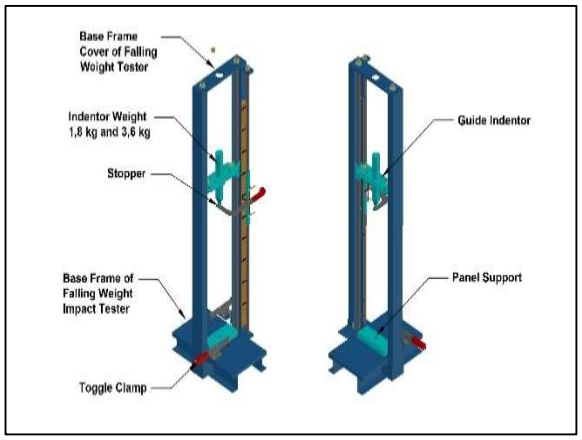

Fig. 5. Configuration of the Developed Falling-Weight Impact Testing Apparatus

The developed falling-weight impact testing apparatus consists of several components designed to comply with the requirements of ASTM D2794-93. Each component performs a specific function to ensure safe operation, testing stability, and reliable measurement of coating impact resistance.

1. Pendulum/Indenter

The pendulum (impactor) is the primary component responsible for transferring impact energy to the coated specimen. It is equipped with a 15.9 mm diameter hemispherical indenter, conforming to the dimensional specifications of ASTM D2794-93. To accommodate different impact energy levels, the apparatus employs two interchangeable impact masses of 1.8 kg and 3.6 kg. The 3.6 kg configuration is achieved by attaching an additional 1.8 kg modular weight to the base impactor, allowing quick assembly and disassembly while maintaining operational flexibility. The design of the pendulum/indenter is presented in Figure 6.

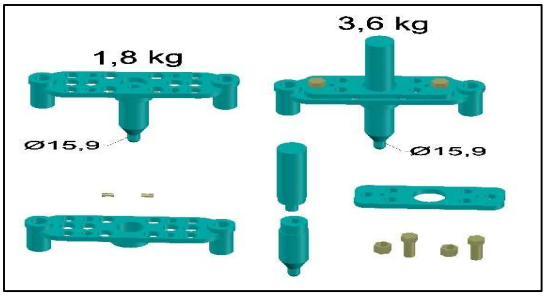

Fig. 6. Design of Identer

2. Guide Indenter/ Guide Rail Assembly

The guide rail assembly is designed to ensure that the impactor travels vertically and strikes the coated specimen precisely at the designated impact location. The assembly incorporates two hardened steel guide shafts and two precision bushings, which minimize lateral movement and maintain alignment throughout the free-fall motion. This configuration enhances the stability, accuracy, and repeatability of the impact test. The design of the guide rail assembly is presented in Figure 7.

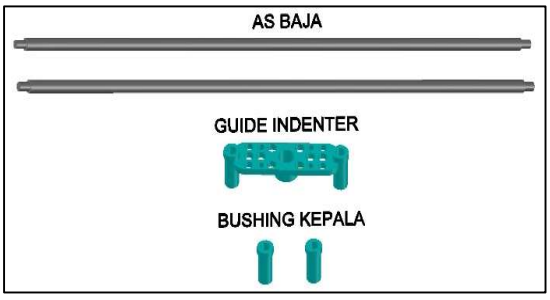

Fig. 7. Design of Guide Indenter

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3. Panel Support

The panel support serves as the specimen holder during the falling-weight impact test, providing stable support throughout the impact event. In accordance with ASTM D2794-93, the support is designed with a 16.3 mm diameter central opening positioned directly beneath the impact point. This configuration allows localized deformation of the specimen while ensuring proper support and consistent impact loading. The design of the panel support is presented in Figure 8.

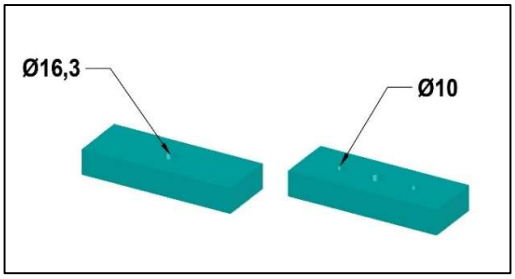

Fig. 8. Design of Panel Support

4. Toggle Clamp

The toggle clamp is used to securely hold the coated specimen in position during impact testing. By preventing specimen displacement or vibration upon impact, the clamp improves the stability, repeatability, and reliability of the test results. The design of the toggle clamp is shown in Figure 9.

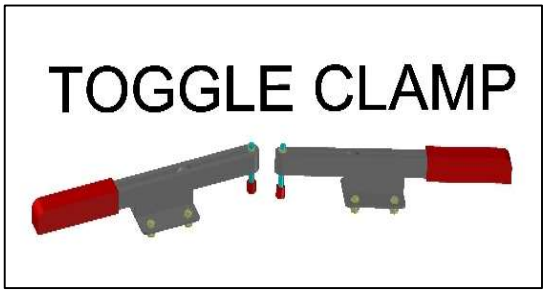

Fig. 9. Design of Toggle Clamp

5. Stopper Mechanism

The stopper mechanism is designed to position and retain the impactor at predetermined drop heights prior to release. This component enables precise adjustment of the drop height, ensuring consistent impact energy and repeatable testing conditions throughout the experimental program. The design of the stopper mechanism is presented in Figure 10.

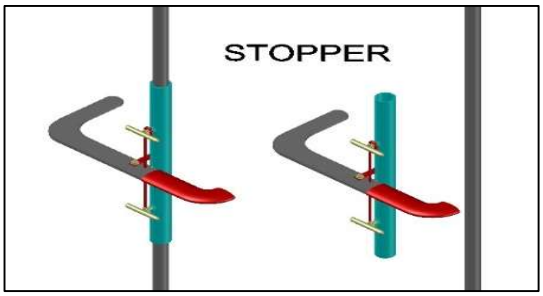

Fig. 10. Design of Stopper Mechanism

3.2 Fabrication of the Falling-Weight Impact Testing Apparatus

The falling weight impact tester was fabricated using CNC machining, precision turning, and SMAW welding processes in accordance with the design specifications. Steel specimens were abrasive blasted to Sa 2½ in accordance with ISO 8501-1 prior to coating application. The coating system was applied under controlled environmental conditions following the manufacturer's technical data sheet, and the dry film thickness was verified before impact testing.

1. The apparatus was manufactured based on the engineering drawings prepared using Autodesk AutoCAD. The fabrication procedure consisted of the following steps:
2. Raw materials and fabrication tools were prepared according to the engineering drawings and manufacturing requirements.
3. The dimensions of each component were marked on the raw material using a steel marker and engineer's square.
4. Structural components were cut to the required dimensions using an angle grinder, followed by edge finishing to remove burrs and improve surface quality.
5. Hole locations were marked using a center punch, and drilling operations were performed according to the specified dimensions and positions.
6. The fabricated components were assembled through a fit-up process and temporarily secured by tack welding using the shielded metal arc welding (SMAW) process to maintain dimensional alignment.
7. Dimensional accuracy, squareness, and levelness were verified using measuring instruments, including a vernier caliper, engineer's square, spirit level, and measuring tape.
8. The impactor (pendulum) was machined on a lathe to produce a 15.9 mm diameter hemispherical tip, in accordance with ASTM D2794-93. An additional modular weight was also manufactured to increase the impact mass from 1.8 kg to 3.6 kg.
9. The machined impactor subsequently underwent a hardening heat treatment to achieve a surface hardness of approximately 60 HRC, thereby improving wear resistance and maintaining dimensional stability during repeated impact testing. The impact indenter was manufactured from DC53 tool steel and subjected to a full hardening heat treatment to achieve a hardness of 58–60 HRC. The heat treatment consisted of two-stage preheating at 650°C and 850°C (2 h each), followed by austenitizing at 1030°C for 2 h and subsequent air

quenching. To relieve residual stresses and improve toughness, double tempering was performed at 500°C and 570°C for 4 h each, resulting in a tempered martensitic microstructure with fine carbide precipitation. This heat treatment provided high hardness, excellent wear resistance, and sufficient toughness to withstand repeated impact loading without permanent deformation of the indenter.

10. The impactor masses were verified using a Vishal VS-6018 digital weighing scale (40 kg capacity) to ensure that the interchangeable impact masses of 1.8 kg and 3.6 kg complied with the design specifications, as presented in Figure 11.

Fig. 11. 1.8 kg and 3.6 kg impactor

11. A 16.3 mm diameter central opening was machined in the panel support in accordance with the dimensional requirements specified in ASTM D2794-93.
12. The structural frame of the apparatus was permanently assembled by shielded metal arc welding (SMAW) using Kobelco RB-26 E6013 electrodes with a diameter of 2.6 mm.
13. After welding, slag was removed using a chipping hammer and steel wire brush, followed by surface finishing with an angle grinder to obtain clean and uniform weld joints.
14. A functional test was conducted to verify that all mechanical components operated properly and that the apparatus performed as intended under the designed operating conditions, it's presented in Figure 12.

Fig. 12. Operational Performance Testing

15. Surface finishing began with the application of an epoxy primer, followed by a polyester body filler to eliminate surface irregularities. The surface was subsequently wet-sanded using 2000-grit abrasive paper to achieve a smooth finish prior to top coating.
16. The apparatus was then painted using a gray finish for the base frame and blue for the impactor and panel support to improve component visibility during testing. A clear coat was subsequently applied to enhance scratch resistance and improve the durability of the painted surface.

Fig. 13. Assembly of the Falling-Weight Impact Coating Testing Apparatus

17. Finally, all components presented in Figure 13, including the guide rail assembly, impactor, panel support, stopper mechanism, and toggle clamp, were assembled onto the base frame to complete the falling-weight impact testing apparatus. The guide shafts were lubricated using Singer lubricating oil to reduce friction between moving components, ensuring smooth vertical movement of the impactor and improving the stability and repeatability of the impact test.

3.3 Preparation of Coated Test Specimens

The test specimens were fabricated from SS400 structural steel with dimensions of 100 mm × 100 mm × 6 mm. The specimens were coated with Jotun Marathon HXB using the air spray coating method to achieve a target dry film thickness (DFT) of 900 ± 100 μm for the primer coating, in accordance with the experimental design.

The specimen preparation and coating procedures were performed as follows:

1. Specimen preparation: SS400 steel plates with dimensions of 100 mm × 100 mm × 6 mm were prepared for the falling-weight impact tests.
2. Surface preparation: The specimen surfaces were subjected to abrasive blasting to remove rust, mill scale, and other surface contaminants while simultaneously producing the required surface profile to enhance coating adhesion. This process using General Abrasive Material Steel Grit (G25). Proper surface preparation is essential for achieving uniform coating performance and ensuring reliable impact test results.
3. Blast-cleaning inspection: The blasted surfaces were visually inspected by comparison with the reference photographs specified in SSPC-VIS 1, Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning. If the required surface cleanliness was not achieved, the specimens were re-blasted until the specified surface preparation standard was satisfied.

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4. Coating application: A primer coating of Jotun Marathon XHB was applied to the prepared steel surfaces using the air spray coating method to achieve the target coating thickness.
5. Wet film thickness (WFT) measurement: Immediately after coating application, the wet film thickness (WFT) was measured using a wet film thickness gauge to verify that the applied coating thickness corresponded to the target 900 ± 100 µm dry film thickness.
6. Dry film thickness (DFT) measurement: After complete curing, the coating thickness was measured using an Elcometer coating thickness gauge to confirm that the final dry film thickness (DFT) satisfied the specified coating requirements prior to impact testing, presented in Figure 14.

Fig. 14. Dry Film Thickness Test

The relatively high dry film thickness (900 ± 100 µm) contributes significantly to the impact response by providing a larger coating volume capable of absorbing impact energy before it is transferred to the steel substrate. Jia et al. reported that increasing epoxy coating thickness from 0.5 to 1.0 mm enhanced the coating's energy absorption capability under impact loading, demonstrating that thicker coatings dissipate a greater portion of the applied impact energy [11].

3.4 Impact Testing Procedure and Failure Assessment

The impact resistance of the coating was evaluated using the developed falling-weight impact testing apparatus with two impact masses (1.8 kg and 3.6 kg) and three drop heights (0.50 m, 0.70 m, and 0.90 m). The coated specimens consisted of SS400 steel plates coated with Jotun Marathon HXB primer having an average dry film thickness (DFT) of 961.67 µm. The testing procedure was performed in accordance with ASTM D2794-93 as follows:

1. The coated specimen was placed on the panel support, which provided stable support throughout the impact test.
2. The required impact mass (1.8 kg or 3.6 kg) was installed according to the experimental conditions, presented in Figure 15.

Fig. 15. Impact Mass 1.8 kg and 3.6 kg

3. The impact location was predetermined, and the specimen was securely fixed using the toggle clamp to prevent movement during testing. It's presented in Figure 16.

Fig. 16 Specimen Test Points and Toggle Clamp Clamping

4. The drop height was adjusted to 0.50 m, 0.70 m, or 0.90 m using the stopper mechanism, which was then locked to ensure accurate positioning of the impactor before release.
5. The stopper was released, allowing the impactor to fall freely and strike the coated specimen.
6. After impact, the coating surface was visually examined using a 40× LED magnifying loupe to identify impact-induced damage, including cracking, indentation, and coating delamination. The observations were documented and used for subsequent analysis of coating failure, presented in Figure 17.

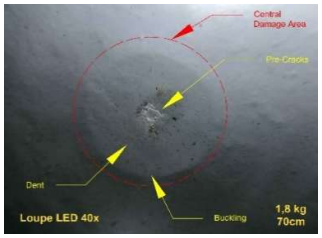
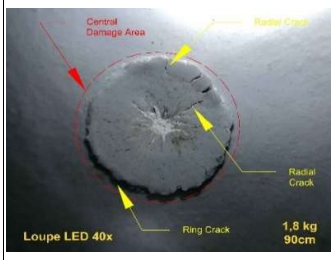
Fig. 17 Inspection of Test Results Using a 40× LED Loupe Magnifier

The coated specimens had an average dry film thickness (DFT) of 961.67 µm. Following the falling-weight impact test, the coating surface was visually inspected using a 40× LED magnifying loupe to identify the presence of cracks in accordance with the evaluation procedure specified in ASTM D2794-93, as shown in Table 1.

The impact resistance of the coating was assessed based on the presence or absence of visible cracking in accordance with ASTM D2794-93. The influence of impact mass and drop height on coating performance was subsequently analyzed to determine the coating's resistance to impact-induced mechanical damage and to identify the corresponding failure mechanisms.

Based on the impact energy equation presented in the previous section, the applied impact energy was calculated for each combination of impact mass and drop height employed in the experiments. These calculations were performed to quantify the applied impact energy transferred to the coated specimens under each testing condition.

Table 1. Visual Inspection Results of The Falling-Weight Impact Coating Tests.

Visual Inspection	Results
	The coating exhibited only dent formation without any visible signs of cracking. Consequently, additional impact tests at higher drop heights are required to determine the coating's threshold for impact-induced failure.
	The coating exhibited only dent formation, with no evidence of cracking. Therefore, further impact testing at greater drop heights is necessary to determine the threshold at which impact-induced coating failure occurs.
	The dented area became more pronounced, while the buckled region propagated into a ring crack, accompanied by radial cracks extending from the ring crack perimeter and the center of the impact dent. These damage features indicate that the coating layer reached its impact failure threshold at a drop height of 90 cm.

Visual Inspection	Results
	The impact coating test conducted with a 3.6 kg pendulum mass at a drop height of 50 cm revealed that increasing the pendulum mass from 1.8 kg to 3.6 kg produced greater impact energy, thereby intensifying the extent of coating damage. The damage was characterized by the formation of a central dent accompanied by radial and edge cracks within the central damage area, together with buckling around the periphery of the dented region.
	The coating exhibited a larger dented area accompanied by buckling along the perimeter of the dent. Furthermore, the radial and edge cracks in the central damage area showed significant propagation, as indicated by increases in both crack length and crack width relative to those observed in the 50 cm drop height test.
	The inspection results of the impact coating test using a 3.6 kg pendulum mass at a drop height of 90 cm indicated that the buckling region had evolved into a ring crack, accompanied by larger radial cracks propagating from the ring crack. This damage progression resulted in coating spalling within the central damage area. Furthermore, radial and edge cracks remained evident at the center of the impact zone, collectively forming a multiple-crack pattern.

The calculated applied impact energy values for all experimental conditions are summarized in Table 2.

https://doi.org/10.29165/ajarcde.v10i3.1188

Table 2. Calculated Applied Impact Energy for Different Impact Masses and Drop Heights.

No	Applied Load (kg)	Height (cm)	Applied Impact Energy (*Joule*)
1	1,8	50	8,83
2	1,8	70	12,36
3	1,8	90	15,89
4	3,6	50	17,65
5	3,6	70	24,71
6	3,6	90	31,77

As shown in Table 1, the applied impact energy increased with both increasing impact mass and drop height, consistent with the theoretical relationship between gravitational potential energy and applied impact energy. The maximum applied impact energy corresponding to each test condition is illustrated in Figure 18, providing a comparison of the energy levels applied during the falling-weight impact tests.

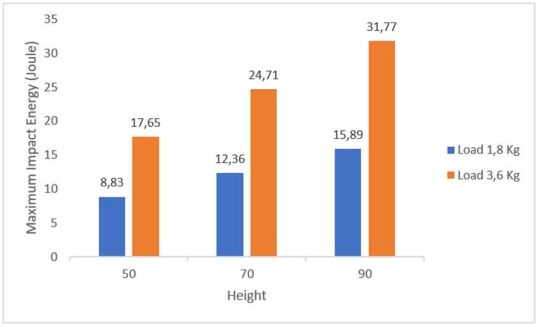


Fig. 18 Maximum Applied Impact Energy as A Function of Impact Mass and Drop Height.

A significant transition in the coating damage mechanism was observed at an impact energy of 15.89 J, indicating the change from a deformation-dominated response to a fracture-dominated response. At lower impact energies (8.83–12.36 J), the coating dissipated the applied energy primarily through localized indentation, resulting in dent formation with limited radial and edge cracks. However, at 15.89 J, circumferential buckling developed around the dented region, suggesting that the compressive stress beneath the indenter had exceeded the local stability limit of the coating. Simultaneously, stress redistribution generated circumferential tensile stresses that initiated crack propagation, representing the onset of brittle fracture. This behavior is consistent with Hertzian contact fracture theory, which states that increasing contact stress promotes the transition from localized deformation to ring crack initiation and subsequent radial crack propagation [10].

The thick epoxy coating (DFT = 900 ± 100 µm) also contributed to this damage evolution. Compared with conventional thin coatings, the greater coating thickness enables higher impact energy absorption through elastic deformation but also generates larger through-thickness stress gradients under localized impact loading. Once the stored strain energy exceeds the fracture toughness of the coating, the damage mechanism progresses from dent formation to buckling, followed by ring crack, radial crack, and ultimately coating spalling. Similar damage evolution has been reported for thick coating systems subjected to Hertzian contact loading [10][11].

4. CONCLUSION

The falling-weight impact tester developed in this study successfully complied with the dimensional requirements of ASTM D2794-93 and reliably generated applied impact energies ranging from 8.83 to 31.77 J with stable, accurate, and repeatable performance. The experimental results demonstrated that increasing the impact mass and drop height increased the applied impact energy, leading to progressively more severe coating damage. Under the present testing conditions, brittle coating fracture was initiated at an applied impact energy of 15.89 J, marking the transition from localized deformation to fracture-dominated damage, while the highest applied impact energy (31.77 J) produced extensive ring and radial cracks, indicating that the coating had reached its impact failure threshold. These findings confirm that applied impact energy is the primary factor governing coating failure and demonstrate that the developed apparatus is a reliable and cost-effective tool for laboratory-scale evaluation of coating impact resistanc

REFERENCE

[1] ASTM International, ASTM D2794-93(2019): Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). West Conshohocken, PA, USA: ASTM International, 2019.

[2] Debrita, Cicilia. "Analisis Pengaruh Variasi Metode Coating pada Pelat Baja ASTM A36 terhadap Prediksi Laju Korosi, Kekuatan Adhesi dan Ketahanan Impact." (2017).

[3] -Budiarto, U., Manik, P., & Kusuma, G. A. (2024). Analisis Penerapan Coating Pada Baja ASTM A36 Dengan Variasi Cat Terhadap Laju Korosi , Kekuatan Adhesi Dan Ketahanan Impact Coating. 15(3), 1253–1269. https://doi.org/10.21776/jrm.v15i3.1500

[4] Fakhri, A. P. N., Manik, P., & Amiruddin, W. (2024). Analisis Perbandingan Penggunaan Nanopartikel Zinc Oxide (ZnO). 12(4), 1–9.

[5] Batista, J. C. A., Godoy, C., & Matthews, A. (2003). Impact testing of duplex and non-duplex (Ti , Al) N and Cr – N PVD coatings. c, 353–361.

[6] Wang, T., Zha, X., Chen, F., Wang, J., Li, Y., & Jiang, F. (2021). Mechanical impact test methods for hard coatings of cutting tools: a review. International Journal of Advanced Manufacturing Technology, 115(5–6), 1367–1385. https://doi.org/10.1007/s00170-021-07219-8

[7] Zhang, L., Wang, Y., Fan, W., Gao, Y., Sun, Y., & Bai, Y. (2020). A Simulation Study on the Crack Propagation Behavior of Nanostructured Thermal Barrier Coatings with Tailored Microstructure. 10(8), 722; https://doi.org/10.3390/coatings10080722

[8] Chen, L., Zou, C., Zang, M., & Chen, S. (2023). Single-Impact Failure of Multi-Layered Automotive Coatings : A Finite Element-Based Study. 13(2), 309; https://doi.org/10.3390/coatings13020309

[9] ASTM D5420-04. (1996). Standard Test Method for Impact Resistance of Flat, Rigid Plastic Specimens by Means of a Falling Weight. ASTM Book of Standards, i, 1–0. https://doi.org/10.1520/D5420-04.2

[10] Wang, X. Y., Li, L. K. Y., Mai, Y. W., & Shen, Y. G. (2008). *Theoretical analysis of Hertzian contact fracture: Ring crack initiation*. Engineering Fracture Mechanics. https://doi.org/10.1016/j.engfracmech.2008.03.003

[11] Jia, Caixia & Yang, Tianyu & Wang, Qian & Li, Zhixin & Yan, Chao & Liu, Xin. (2026). Effect of thickness variation on impact damage characteristics of indicative coatings. Journal of Coatings Technology and Research. 10.1007/s11998-025-01256-8.