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Abstract

The rapid adoption of Modern Methods of Construction (MMC) in the United Kingdom has introduced new challenges in ensuring structural rigidity, particular in light-gauge steel structures. This study investigates the impact of fastener installation methods on the mechanical performance of connections in MMC applications, addressing a critical knowledge gap in the industry.

The research focused on comparing the performance of self-drilling, self-tapping fasteners installed using traditional electric screwdrivers and increasingly popular impact-type screwdrivers. Two standardised test series based on EAD 330046-01-0602 were conducted to determine the characteristic lap-shearing resistance and characteristic withdrawal resistance of fastener connections.

Test specimens were prepared using stainless-steel fasteners (EN 1.4301) and cold-rolled mild structural steel (S350GD+Z) in various thicknesses, representing common MMC configurations. A total of 500 tests were performed using a calibrated universal testing machine, with rigorous quality control measures implemented throughout the experimental process.

Results revealed significant reductions in fastener performance when impact screwdrivers were used for installation. Withdrawal resistance decreased by 34.71% to 59.71%, while lap-shearing resistance reduced by 47.85% to 70.65% compared to traditional installation methods. Statistical analysis confirmed the significance of these findings, with all tests falling within ± 3.0 standard deviations in Z-score analysis.

These results have profound implications for the structural integrity of MMC units. Connections designed based on traditional installation assumptions may be significantly under strength when impact screwdrivers are used, potentially leading to premature structural failures. The research highlights the need for updated design guidelines,

stricter quality control in MMC fabrication, and potential revisions to building codes and standards.

The research also establishes a foundation for future studies, including investigations into the long-term effects of installation methods on fastener performance, coating integrity and overall structural health. The findings underscore the importance of proper installation techniques in ensuring the safety and reliability of MMC structures.

This research contributes valuable insights to the field of fastener technology in MMC and calls for immediate action from industry stakeholders to address the identified issues. The results provide a basis for updating fastener selection and installation guidelines for MMC applications, ultimately enhancing the structural performance longevity of light-gauge steel structures in innovative construction techniques.

Introduction and literature review

1. Introduction and knowledge gap

The construction industry is undergoing significant transformations in the 21st century, with Modern Methods of Construction (MMC) gaining prominence[01]. These evolving construction techniques, particularly those involving light-gauge mild structural steels, present new challenges for fastener performance and longevity[02]. As the uptake of MMC is projected to increase in the coming years[03], there is an urgent need to address the knowledge gap regarding fastener behaviour in these novel applications.

Previous studies, notably the research conducted by Brandner et al[04] and Ringhofer[05], have established that axially-loaded screws resisting withdrawal can provide significant load-carrying capacities and stiff connections[06]. However, this body of research primarily focusses on timber substrates, highlighting a critical knowledge gap concerning light-gauge mild structural steels commonly used in MMC[07]. The different material properties of steel compared to timber, such as hardness, yield strength and tensile strength, necessitates a re-evaluation of traditional fastening methodologies and their long-term efficacy.

2. Installation tooling and mechanical performance

Furthermore, there is limited research on the effects of different power tools used for fastener installation. While the construction industry has traditionally relied on electric screwdrivers[08], there is an increasing trend towards the use of impact-type tooling[09]. This shift raises important questions about the localised mechanical performance of fasteners installed using these tools and the potential long-term implications for structural integrity, especially in light-steel panel and modular systems[10].

This research explores how the mechanism of installation significantly influences fastener performance. Impact-type screwdrivers, which apply force along the fastener's axis parallel to the substrate, affect the fastener and substrate differently compared to traditional methods[11]. Beyond the potential ergonomic concerns related to operators' wrist deviation[12], this research aims to elucidate the mechanical performance implications of using impact-type tooling.

3. Structural Health Monitoring (SHM) and statutory regulation

To address these concerns, Structural Health Monitoring (SHM) techniques offer promising avenues for the assessment of long-term fastener performance[13], which will be explored in future research that utilises this research as a basis of localised mechanical performance and for future experimental design. SHM methodologies, such as Acoustic Emission Monitoring (AEM) and piezo-electric sensing, can provide valuable insights into the progression of fastener connection degradation over time[14]. These techniques are particularly relevant for MMC applications, where early detection of potential issues can be resolved prior to any failures in-situ[15].

The construction industry is governed by stringent standards and regulations to ensure structural safety and performance[16]. However, the rapid evolution of construction methods and materials necessitates a continuous re-evaluation of these standards[17]. Current regulations, may not fully account for the unique challenged posed by MMC and the use of light-gauge steel substrates, highlighting the need for research-driven updates to existing guidelines[18].

Looking to the future, emerging trends in fastener technology, such as self-healing coatings and fastener connections with embedded sensors, offer potential solutions to some of the challenges identified[19]. However, these innovations require thorough investigation to ensure their efficacy and compatibility with various construction methods and materials, particularly those employed in MMC[20].

4. Significance of this research

The aim of this study is to comprehensively evaluate the performance of fasteners in light-gauge mild structural steels, typically used in MMC, with a focus on the effects of different installation methods. The specific objectives are to: (1) compare the mechanical performance of fasteners installed using traditional and impact-type tooling; (2) assess and establish the basis for future large-scale SHM tests on fastener connections where long-term implications of installation methods on fastener durability and structural integrity are established; and (3) provide recommendations for updating fastener selection and installation guidelines for MMC applications.

This research will not only contribute to the body of knowledge on fastener performance in MMC but also provide practical insights for the construction industry. By addressing the gap between current practices and the specific requirements of light-gauge steel structures, this study aims to enhance the reliability and longevity of MMC projects, ultimately supporting the broader adoption of these innovative construction techniques.

Methodology

To address the primary aim of evaluating fastener performance in light-gauge mild structural steels used in MMC, with a particular focus on installation methods, two standardised tests were designed on prominent industry standards. These tests directly support objective (1) by enabling a comparison of mechanical performance between traditional and impact tooling installation methods. The characteristic lap-shearing resistance and the characteristic withdrawal resistance were determined according to the procedures defined in European Assessment Document (EAD) 330046-01-0602[21].

1. Test specimen preparation

All materials were sourced from certified suppliers and conformed to relevant industry standards, ensuring the validity of results for real-world MMC applications in support of objective (3). Fasteners used were Evolution Fasteners (UK) Ltd Part No. BMTSPH5.5-25-3, made of stainless steel (EN 1.4301 pursuant to BS EN 10088-2:2014). These fasteners were chosen as they represent the most common type for affixing light-gauge mild-steel structural sections in typical MMC applications[22], aligning with the researches focus on MMC.

The fasteners, approximately 5.5mm x 25.0mm (nominal diameter x overall length) came with a Declaration of Performance pursuant to BS EN 14566: 2008 & A1: 2009. Cold-rolled mild structural steel (grade S350GD+Z pursuant to BS EN 10346: 2015) was supplied by Metal Supermarkets Ltd, with nominal thicknesses of 0.6mm, 1.0mm, 1.2mm, 1.5mm and 2.0mm. This range of thicknesses allows for a comprehensive evaluation of fastener performance across various configurations of sections found in MMC.

Quality control checks, including visual and measurement inspections, were performed to ensure specimen integrity and compliance with their respective standards. This rigorous approach supports the reliability of the data for future SHM tests (objective (2)) and for developing updates guidelines (objective (3)).

Specimens were configured for lap-shearing and withdrawal tests as per EAD 330046-01-0602. Fastener installation followed BS EN ISO 10666: 1999, with controlled installation speed (500 – 750 RPM) and angle (within 5° of normal). Two installation tools were used to address objective (1):

(a) Traditional-type: Makita FS2500 (0 – 2,500 RPM, 0 impacts per minute),

(b) Impact-type: Makita DTD172 (0 – 2,100 RPM, 1,100 impacts per minute).

A total of 500 tests (250 each for lap-shearing and withdrawal resistance were performed, providing a robust dataset for comparative analysis (objective (1)) and future SHM studies (objective (2)).

2. Test set-up and equipment

The experiments were conducted on a Shimadzu Corporation AGS-X universal testing machine with a 10.0 kN Class 0.5 load cell, calibrated to BS ISO 376: 2011. As shown in Figure 1, fixturing consisted of a custom-designed jig for withdrawal resistance tests while lap-shearing resistance tests were gripped directly in the universal testing machine using flat-grips. Fixtures were validated prior to the tests using proof-of-concept tests to the full range of the 10.0kN load cell without any slippage or deformation issues. Deflection of the jig was tested at 10.0kN using a calibrated linear probe and found to be less than the detectable limit of 0.1mm, thus the jig and fixtures for both tests were validated as sufficiently rigid.

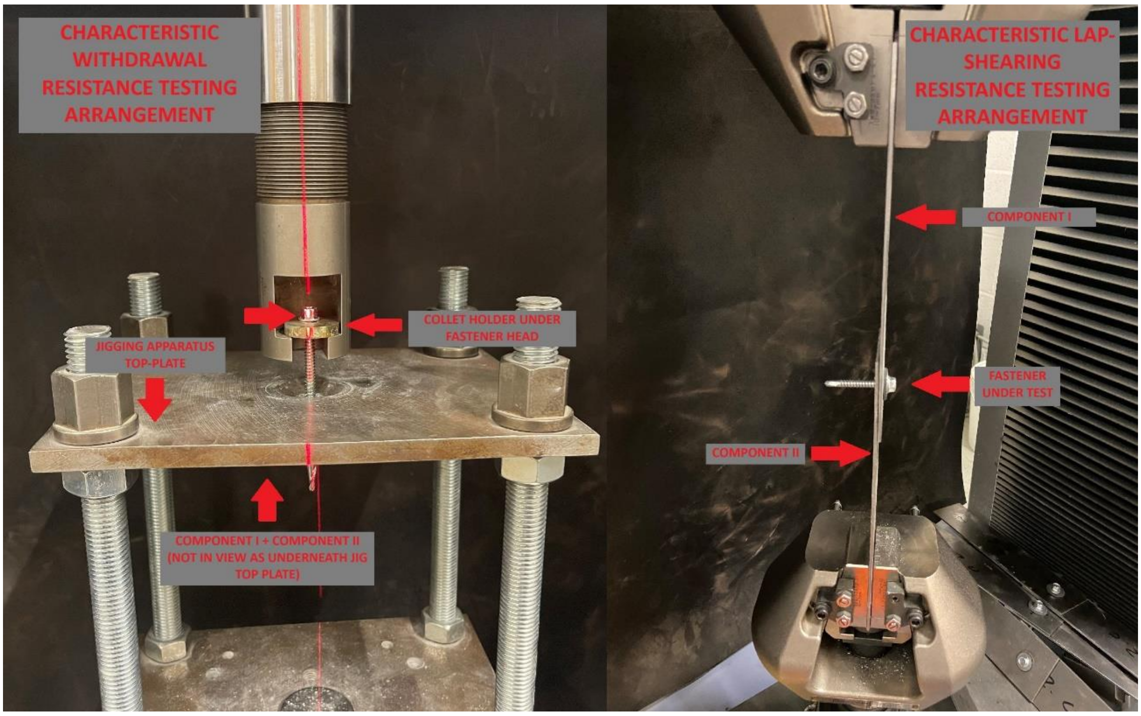

Figure 1 – Typical arrangements of characteristic withdrawal and lap-shearing resistance tests.

Displacement was recorded using the linear transducer built-in to the Shimadzu AGS-X universal testing machine. Data was recorded using the integrated Trapezium X software at the maximum sampling rate pf 1,000 Hz. Data was recorded and exported to Microsoft Excel as a table showing the maximum force recorded for each test as well as the maximum displacement with corresponding force vs displacement graphs.

3. Characteristic lap-shearing test

Specimens were mounted in the flat grips, ensuring that the axis of loading was perpendicular to the fastener using a calibrated laser line level which shot a beam across the vertical plane of the test as well as horizontally across the fastener to ensure loading was perpendicular. The grips were tightened manually to ensure that slippage was avoided. Any pre-load attributed to the tightening was not removed prior to the test starting and was noted as nominal for each specimen (i.e., less than 0.05 kN). The load was applied steadily at a rate of 0.450 kN/min until failure occurred. The failure criteria were set as when maximum load was reached, or there was a sudden drop in the load, or when excessive deformation meant a rotation of the screw beyond 45° from its' starting position.

4. Characteristic withdrawal resistance

Specimens were mounted in a custom-jig where the head of the screw was restrained using a collet system to the crosshead of the universal testing machine and the substrate was restrained from movement by contact with the upper-plate of the jig. Axial alignment of the screws with the direction of loading was ensured using a calibrated laser line level which shot a beam up the screw shank vertically and aligned with the centre line of the load cell. The collet system meant that alignment was maintained through the whole test cycle. The cross-head of the universal testing machine was manually moved until the topside of the substrate was approximately 0.5mm from the underside of the jig top-plate, as such there was no preloading prior to the tests starting. The load was applied steadily at a rate of 0.450 kN/min until failure occurred. The failure criteria were set as when maximum load was achieved or there was a sudden drop in the load.

5. Data recording, statistical analysis and repeatability check

Load displacement curves for each test was recorded as well as the maximum load achieved. Notes on the failure mode observed was documented on the test results. Characteristic values for both series of tests were calculated pursuant to EAD 330046-01-0602 as well as the mean, standard deviation and measurement uncertainty.

A comparative analysis was performed to compare the results between traditional-type and impact-type installation tooling. The percentage difference in characteristic values was calculated as well as statistical significance of the results. Repeatability was established using a Z-score analysis, where all tests passed within ± 3.0 standard deviations, further validated the methodology, ensuring that the results can be confidently used to inform future research and industry practices.

This methodology provides a rigorous framework for evaluating the impact of installation methods on fastener performance on light-gauge steel structures used in MMC. The results obtained from these tests directly address the research objectives and contribute valuable insights to the field of fastener technology in MMC.

Results and analysis

The experimental work and subsequent statistical analysis strongly support the research hypothesis developed from the literature review: the use of impact-type tolling leads to several negative outcomes in fastener performance, particularly in light-gauge mild structural steels commonly used in MMC.

Statistical analysis, including descriptive statistics (average, mean, standard deviation and standard error, analysis of variance (single-way ANOVA), analysis of covariance, and regression analysis, was performed using Microsoft Excel to validate the research hypothesis.

To ensure the reliability and repeatability of the test procedures, Z-scores were calculated following the methodology outlined in UKAS Document M3003[23]. All experiments yielded Z-scores within ± 3.0 standard deviations of the mean, validating the test procedures in accordance with the bandings used in ISO/IEC 17043: 2023. This rigorous approach aligns with the emphasis on structural safety and performance standards highlighted in the literature review.

One-way ANOVA further substantiated the research hypothesis, revealing that both characteristic withdrawal and lap-sharing resistances of the fasteners installed using impact-type tooling were statistically significantly lower ($p < 0.001$) than those installed with a traditional electric screwdriver. This finding addresses the first objective of this research: comparing the mechanical performance of fasteners installed suing traditional and impact-type tooling.

As illustrated in Figure 2, the characteristic withdrawal resistance is substantially reduced when fasteners are installed using an impact-type screwdriver compared to a traditional electric screwdriver. The percentage reduction in connection strength ranges from 34.71% to 59.71%, varying with the thicknesses of components I and II and their orientation relative to the fastener penetration sequence. This significant reduction in performance aligns with the literature review's emphasis on the need for re-evaluation of traditional fastening methodologies in light-gauge steel structures.

Similarly, Figure 3 demonstrates a marked decrease in characteristic lap-shearing resistance for connections where fasteners are installed using an impact-type screwdriver. The reduction in connection strength ranges from 47.85% to 70.65%, again dependent on the summation of component thicknesses and orientation. These findings directly address the second research objective, providing a basis for future large-scale SHM tests on fastener connections where long-term implications of installation methods on fastener durability and structural integrity can be established.

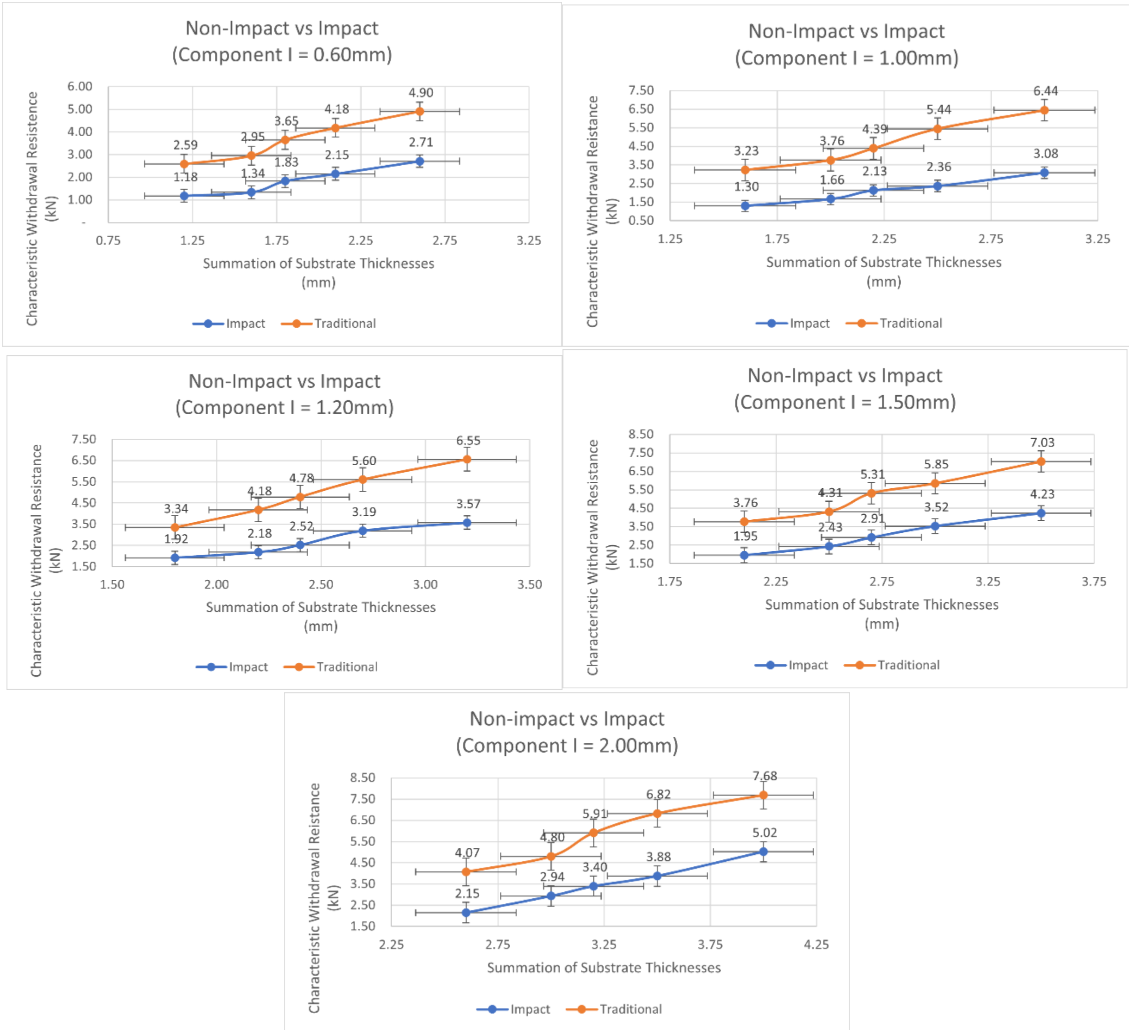

Figure 2 – Comparison of Characteristic Withdrawal Resistances when installed using traditional tooling vs using impact-type tooling.

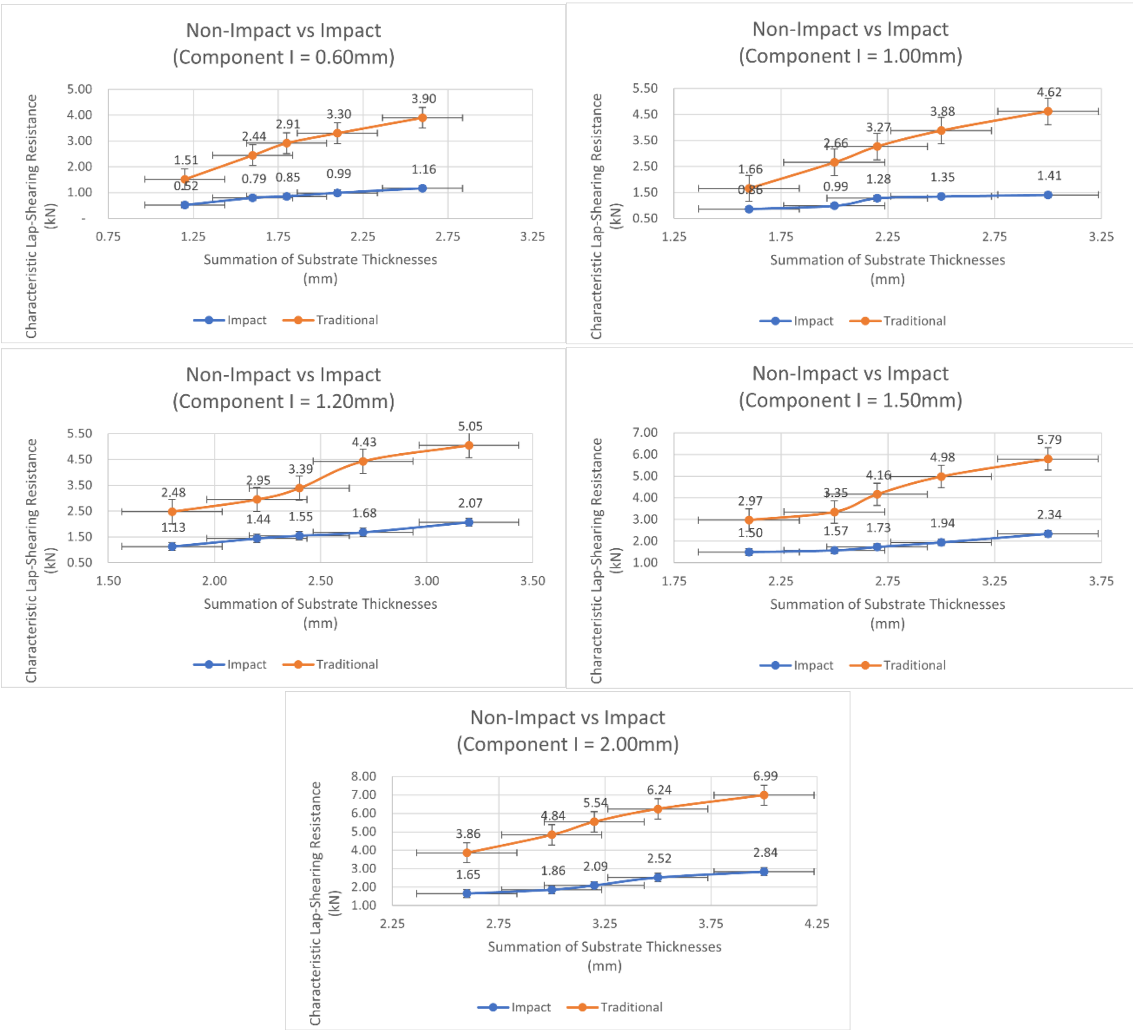

Figure 3 – Comparison of Characteristic Lap-Shearing Resistances when installed using traditional tooling vs using impact-type tooling.

These results underscore the critical importance of installation methods in fastener performance, particularly in MMC applications. The significant reductions in both withdrawal and lap-shearing resistances when using impact-type tooling highlight potential risks to structural integrity that were not previously well-documented in the literature. These findings provide crucial insights for updating fastener selection and installation guidelines for MMC applications, addressing the third research objective.

In conclusion, the results provide empirical evidence supporting the concerns raised in the literature review regarding the effects of different installation methods on fastener performance in light-gauge steel structures. This research contributes to filling the knowledge gap identified earlier and provides a foundation for further investigations into long-term fastener durability and SHM monitoring in MMC applications.

Discussion and conclusions

As noted in literature review, MMC has gained significant popularity in the United Kingdom and with expansion and adoption of these systems expected to grow, introduces new challenges for SHM assessment as once pre-fabricated units are constructed, retrospective inspection of fastener connections is often impossible[24].

This research reveals a critical gap between design assumptions and actual fastener performance when impact screwdrivers are used. Connection strength reductions of 34.71% to 59.71% for withdrawal resistance and 47.85% to 70.65% for lap-shearing resistance were observed with impact screwdriver usage. These findings suggest that connections may not behave elastically as per designer assumptions, potentially leading to premature structural failures.

Practical implications include:

(a) Potential under design of structural connections in MMC units,
(b) Need for stricter quality control in MMC fabrication,
(c) Possible economic impacts due to early replacement or retrofitting of structures,
(d) Necessity for updated building codes and standards.

This issue stems from the concurrent adoption of non-conventional installation tools and MMC techniques, coupled with lack of prior research. Addressing this knowledge gap requires industry-wide training, awareness efforts, and updated guidelines for fastener installation in MMC applications.

Further research is needed to:

1. Investigate other mechanical effects on fasteners,
2. Assess impact on fastener coating integrity,
3. Conduct long-term SHM studies.

In conclusion, this research highlights a critical issue at the intersection of MMC and fastener installation practices. Immediate action from industry stakeholders is crucial to ensure the safety and reliability of MMC structures.

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Data availability statement

The data presented in this study is available on request from the corresponding author.

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