Experimental Investigation of a Brass-Infused Mild Steel Composite: Insights from Quranic Metallurgy (Al-Kahfi 18:96)

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Abstract

Quran 18:96 describes how Dzulqarnain constructed a fortified barrier using piles of iron plates, heated until it red-hot, and subsequently coated with molten copper alloy. Interpreting this verse from a metallurgical perspective, this study investigates the tensile behaviour of a material system inspired by the described process, represented experimentally using mild steel plates and molten brass as the copper-based alloy. The tensile properties of the resulting brass-mild steel metal matrix composite were evaluated and compared with those of brass and mild steel individually. The methodology involves heating mild steel plates, introducing molten brass between them, and allowing the assembly to cool to form a bonded structure. Subsequently, tensile testing was performed to determine parameters such as ultimate tensile strength, yield strength, and strain characteristics. Mechanical test results show that brass exhibits the highest tensile strength (592.12 MPa), followed by mild steel (542.36 MPa), while the metal composite displays a lower tensile strength of 448.57 MPa. Conversely, the metal composite material of brass-infused mild steel specimens demonstrates significantly higher strain values (0.3000) compared to brass (0.1829) and mild steel (0.2176). These findings highlight that brass-infused mild steel forms a novel metal matrix composite with enhanced ductility and strain capacity, despite reduced tensile strength. The improved strain behaviour may offer various advantages in applications that require higher strain properties, impact resistance, or energy absorption. The implications of this work extend beyond materials testing: the experimental findings provide a scientific basis for interpreting the metallurgical insights embedded in Quran 18:96, linking ancient descriptions with modern engineering understanding. Additionally, the study highlights the potential of copper-alloy–infused steel composites for use in structural, protective, and engineering applications where high strain capacity is beneficial. Future work may expand the Quranic metallurgical interpretation by exploring bronze as an alternative copper alloy system to further refine the material representation.

Keywords: Brass-Infused Mild Steel, Iron-Copper Alloy Composite, Metal Matrix Composite (MMC), Quranic Metallurgy, Tensile Properties

1.0 Introduction

The fusion of ancient metallurgical wisdom with contemporary materials science presents an intriguing avenue for research. Surah Al-Kahfi (18:96) of the Quran describes the construction of a robust barrier using heated iron and molten copper alloy (or brass), suggesting early knowledge of composite material fabrication. The verse mentions:

"Bring me sheets of iron" – until, when he had levelled [them] between the two mountain walls, he said, "Blow [with bellows]," until when he had made it [like] fire, he said, "Bring me that I may pour over it molten copper." (18:96)

A previous study by [1] regarding this Quranic metallurgy has described that the use of iron and copper to create a barrier can be seen as an early form of metal-matrix composite. Also, [2] in a review study has provided the translation of copper alloy in this verse as bronze and further elaborates that the metal composite barrier was meant for anti-corrosion purposes. Some other minor translation from Islamic scholars also mentions that the materials are to be as molten lead [3] or molten brass [4]. Either way, in this metal matrix composite material, iron acts as the reinforcement, while copper alloy serves as the matrix. This combination has provided strong and durable material, capable of withstanding significant stress and environmental conditions [5], [6], [7]. This study draws inspiration from this historical reference to explore the mechanical properties of brass-infused mild steel composite.

Mild steel, characterised by its low carbon content, offers a balance of strength, ductility, and weldability, making it a staple in structural applications [8], [9]. Its typical yield strength ranges from 250 to 400 MPa, depending on composition and processing [10], [11]. Brass, an alloy of copper and zinc, is renowned for its corrosion resistance, machinability, and aesthetic appeal. It exhibits a yield strength of approximately 200 MPa and an ultimate tensile strength around 550 MPa [12], [13], [14], [15], [16], [17]. The infusion of molten brass into mild steel could potentially enhance mechanical properties through mechanisms such as solid solution strengthening and the formation of intermetallic compounds [18], [19], [20], [21].

Brass-infused mild steel composites exhibit promising mechanical and wear properties, largely influenced by surface preparation and processing techniques [22]. Enhancements in interfacial bonding, wear resistance, and mechanical strength are achievable through careful control of surface roughness, processing conditions, and composite structure [23], [24]. Despite the widespread use of both materials, limited research has specifically focused on the tensile behaviour of brass-infused mild steel composites. The process of introducing molten brass between heated mild steel plates may result in a unique microstructure, influencing properties such as tensile strength, strain and ductility. Understanding these effects is crucial for assessing the material's suitability for engineering applications. By integrating historical metallurgical practices with modern experimental techniques, this study aims to contribute to the development of novel metal matrix composite materials through experimental. Should the brass-infused steel demonstrate superior mechanical properties, potential applications could extend to structural engineering, automotive components, and other sectors requiring materials that combine strength with ductility. Specifically, the objective of this study is to evaluate and analyse the tensile properties of the composite and compare them with those of brass and mild steel alone.

2.0 Materials and Methods

This study encompasses the fabrication and tensile testing of the composite material. The methodology involves heating mild steel plates, introducing molten brass between them, and allowing the assembly to cool, forming a bonded structure. Subsequent tensile tests determine parameters such as ultimate tensile strength, yield strength, and strain behaviour. These results were then benchmarked against standard brass and mild steel specimens to evaluate enhancements or trade-offs in mechanical performance. This study employs mild steel plates and brass, selected based on their distinct mechanical properties and their potential to create a metal composite material with enhanced performance (Figure 1). Mild steel, widely used in structural applications, has a yield strength ranging from 250 to 400 MPa, offering a balance between strength and ductility. Brass, an alloy of copper and zinc, is known for its corrosion resistance, machinability, and moderate strength, with an ultimate tensile strength of approximately 550 MPa. The inspiration for this combination stems from the Quranic reference in Surah Al-Kahfi (18:96), where molten metal was used to reinforce a structure, providing a historical foundation for exploring its mechanical advantages.

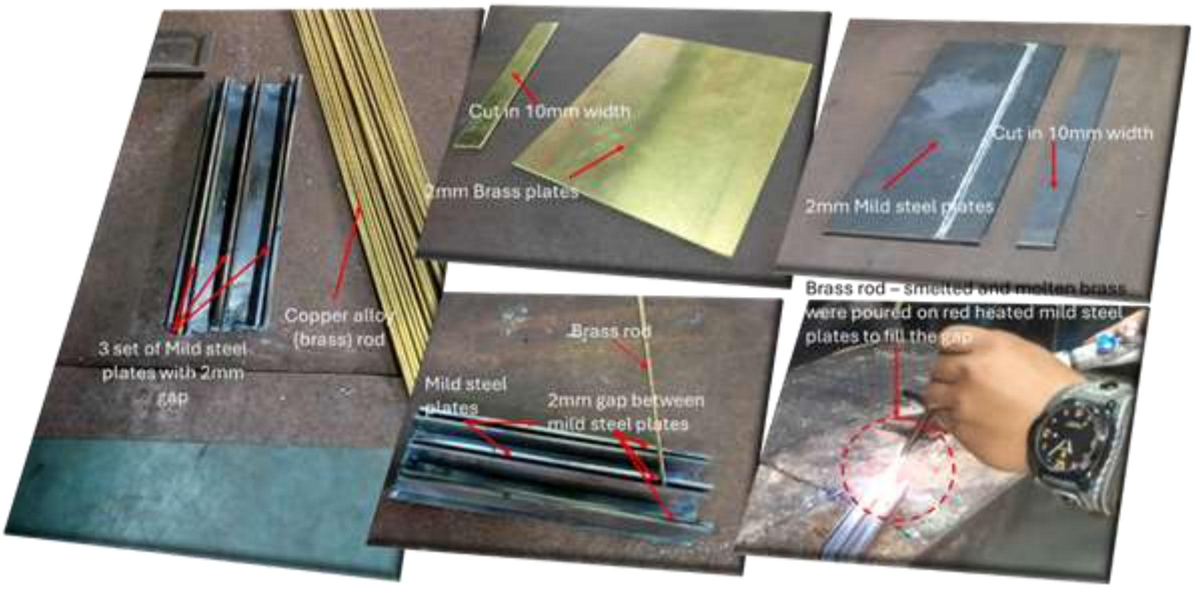

Figure 1: Experimental material and preparation for test specimen fabrication

The fabrication of the brass-infused mild steel composite follows a systematic procedure to ensure optimal bonding and mechanical performance. Two identical mild steel plates (100 mm x 50 mm x 5 mm) are meticulously cleaned to remove oxides, oils, or other surface contaminants that could hinder bonding. The plates are heated at about 1000°C, ensuring they reach the austenitic state that enhances adhesion with molten brass. Brass is melted at approximately 900-950°C and carefully poured between the heated mild steel plates, allowing diffusion and possible metallurgical bonding at the interface. The composite specimen is allowed to cool at room temperature under still-air cooling at room temperature to ensure uniform solidification and prevent defects such as porosity or cracks. The solidified specimens are then machined using a milling machine into standard tensile test samples following ASTM E8 specifications, ensuring consistency and repeatability in testing (Figure 2). Even though careful procedures have been practised, the limitation in experimental material fabrication still occurs because lack of facility to control the high-temperature metal smelting environment, resulting in partial zinc oxide formation. This condition affects parts of the brass infusion process into mild steel surfaces under metal matrix composite laminates, and will be explained with the test results.

Figure 2: Tensile test specimen fabrication using a vertical milling machine

To assess the mechanical performance of the fabricated composite, standardised tests are conducted. A 50 kN Shimadzu universal testing machine (UTM) was used to evaluate ultimate tensile strength (UTS), yield strength, and maximum strain, operating with the support of Trapezium software (Figure 3). The setup follows the standard gripper for plate coupon test, uniaxial tensile loading with a loading rate of 0.3 mm/ min. The test was performed according to ASTM E8 standards to ensure comparability with conventional materials. By integrating these fabrication and testing methodologies, this research aims to establish a fundamental understanding of the mechanical behaviour of brass-infused mild steel composites. The results will provide valuable insights into the potential applications of such materials in structural and engineering applications, bridging the gap between historical metallurgical techniques and modern materials science.

Figure 3: Mechanical test set-up

3.0 Results and Discussion

The tensile properties of the brass-infused mild steel composite (M.S.Brass, BSMMC), pure mild steel (M.Steel, MS), and pure brass (Brass, BS) were analysed through tensile testing. The results include key parameters such as tensile load, displacement, Young's modulus, yield point, tensile strength, tensile strain, and percentage of elongation. The data obtained from the universal testing machine (UTM) are summarised in Table 1.

Table 1: Summary of tensile properties

Specimen	Tensile Load (N)	Displacement (mm)	Young's Modulus (GPa)	Yield Point (MPa)	Tensile Strength (MPa)	Tensile Strain	Elongation (%)
Brass (BS)	4263.23	4.5728	450.64	525.63	592.12	0.1829	18
M.Steel (MS)	3904.98	5.4401	699.80	425.07	542.36	0.2176	22
M.S.Brass (BSMMC)	9689.20	7.4997	223.20	186.00	448.57	0.3000	30

3.1 Tensile Strength and Young's Modulus

The results indicate that brass (BS) has the highest tensile strength (592.12 MPa), followed by mild steel (M.Steel) (542.36 MPa), with the metal composite (M.S.Brass) specimen exhibiting the lowest value (448.57 MPa). The Young's modulus of the composite material (M.S.Brass) (223.20 MPa) falls below the value of brass (BS) (450.64 MPa) and mild steel (MS) (699.8 MPa), suggesting a decrease in stiffness compared to both metals in the metal composite material composition. This condition occurs due to the imperfection in brass infusion between each contact surface of brass and mild steel plates in the metal composite laminates. The main reason behind the imperfection of brass infusion is that some of the zinc elements in brass become oxides under elevated temperature (1000 ^{0}C), thus affecting the bonding between metal plates involved in the material system. The influence of molten brass infusion on the composite's mechanical performance is further analysed through stress-strain curves (Figure 4). Inconsistency during the linear deformation curve in the M.S.Brass specimen revealed that there was imperfection in brass infusion, which affected the whole metal composite material during tensile load application. The stress versus strain curve also shows that brass and mild steel curve data are consistent with literature in terms of Young's modulus, yield point, ultimate strength and failure behaviour.

3.2 Strain and Elongation Analysis

The percentage of elongation and tensile strain of the metal composite material specimen shows significantly higher values (30%, 0.300) compared to pure mild steel (M.Steel) (22%, 0.2176) and brass (18%, 0.1829) alone. This suggests improved ductility, likely due to the metallurgical bonding between brass and mild steel, which accommodates higher deformation before failure. Bar chart in Figure 5 compares the tensile strain among all test specimens and clearly indicates that brass-infused mild steel composite (M.S.Brass) material poses the highest tensile strain value, which is crucial for certain applications that require high-strain materials.

The methodology involves heating mild steel plates, introducing molten brass between them, and allowing the assembly to cool, forming a bonded structure. Subsequent tensile tests determine parameters such as ultimate tensile strength, yield strength, and strain behaviour. These results will be benchmarked against standard brass and mild steel specimens to evaluate enhancements or trade-offs in mechanical performance. This study employs mild steel plates and brass, selected based on their distinct mechanical properties and their potential to create a metal composite material with enhanced performance (Figure 1). Mild steel, widely used in structural applications, has a yield strength ranging from 250 to 400 MPa, offering a balance between strength and ductility. Brass, an alloy of copper and zinc, is known for its corrosion resistance, machinability, and moderate strength, with an ultimate tensile strength of approximately 550 MPa. The inspiration for this combination stems from the Quranic reference in Surah Al-Kahfi (18:96), where molten metal was used to reinforce a structure, providing a historical foundation for exploring its mechanical advantages.

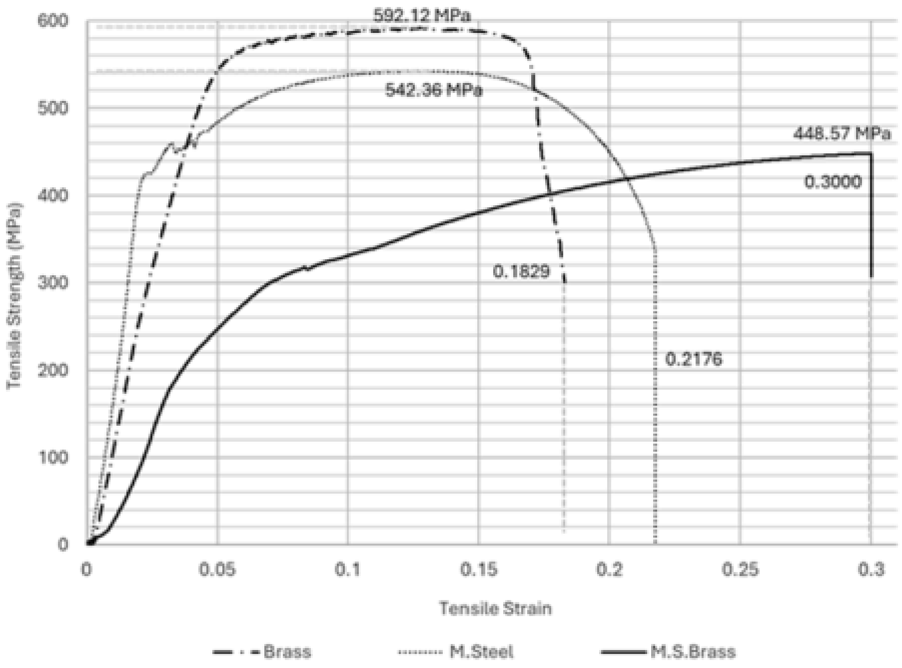

Figure 4: Stress versus strain curve for all test specimens

According to [25], metals with high strain rate are very useful in improving impact resistance and toughness, as well as enhanced ductility, which is important in space exploration and military armour applications. In addition to that, [26] also supports arguments on the advantages of high-strain material to resist ballistic impacts and explosive blasts due to strain hardening behaviour, which will cause large deformation before fracture, thus preventing sudden and catastrophic failure. Another advantage of high-strain materials is in the automotive industry, where metals with high strain rate properties are essential in improving crashworthiness, which helps in absorbing energy during collisions, thereby enhancing passenger safety [27].

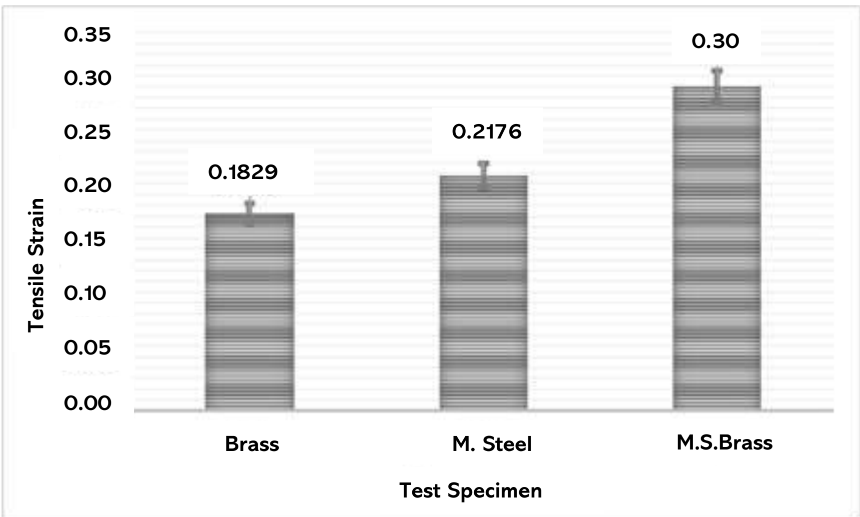

Figure 5: Tensile strain comparison among all test specimens

3.3 Failure Mode Analysis

The failure behaviour of each specimen was examined to understand the fracture characteristics. Figure 6-8 (Failure mode) illustrates the fractured specimens after tensile testing.

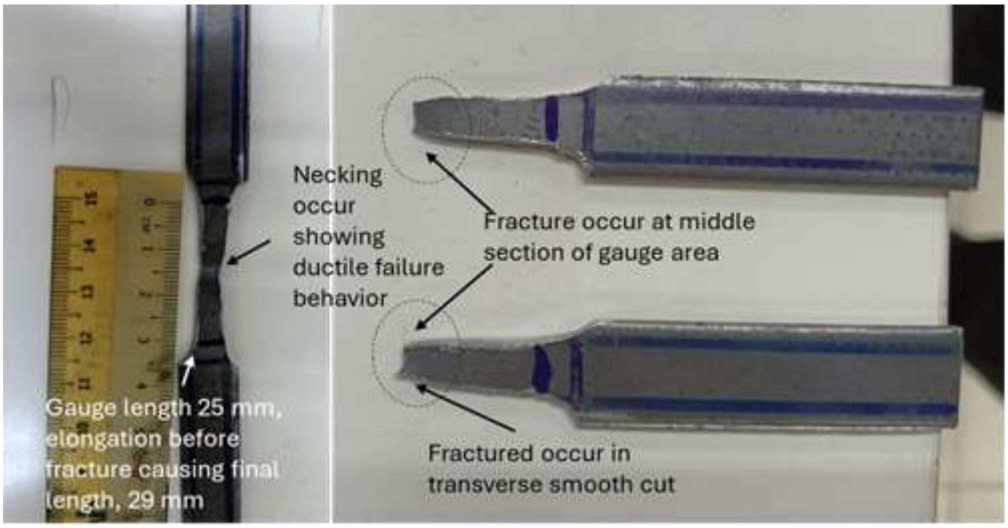

Figure 6: Failure modes of the mild steel test specimen

Figure 6 shows the fractured specimen of mild steel after undergoing tensile testing. The specimen exhibited a clear ductile failure behaviour, characterised by significant necking at the centre of the gauge length. The reduction in cross-sectional area at the fracture zone indicates that the material underwent extensive plastic deformation before failure. The top view of the fracture area seems transverse, smooth cut, but its fracture surface appears rough and uneven, a typical sign of energy absorption during plastic deformation. This failure behaviour is expected from mild steel, which generally possesses good ductility, allowing it to elongate considerably before breaking under tensile stress.

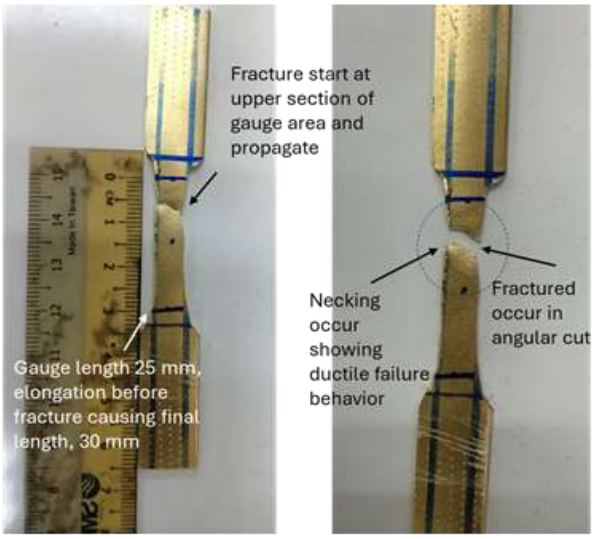

Figure 7:Failure modes of brass test specimen

Figure 7 presents the fractured specimen of brass after tensile testing. The specimen displayed less ductile failure characteristics compared to mild steel, where the fracture occurred with minimal or no visible necking. The fracture location is near the top area where the uniaxial loading was exerted. The top view of the fracture indicates an angular cut, and its surface appears relatively flat and smooth, indicating that the material failed suddenly with limited plastic deformation. This suggests that brass, in this case, has lower ductility compared to mild steel and tends to fracture in a brittle manner when subjected to tensile loading beyond its capacity.

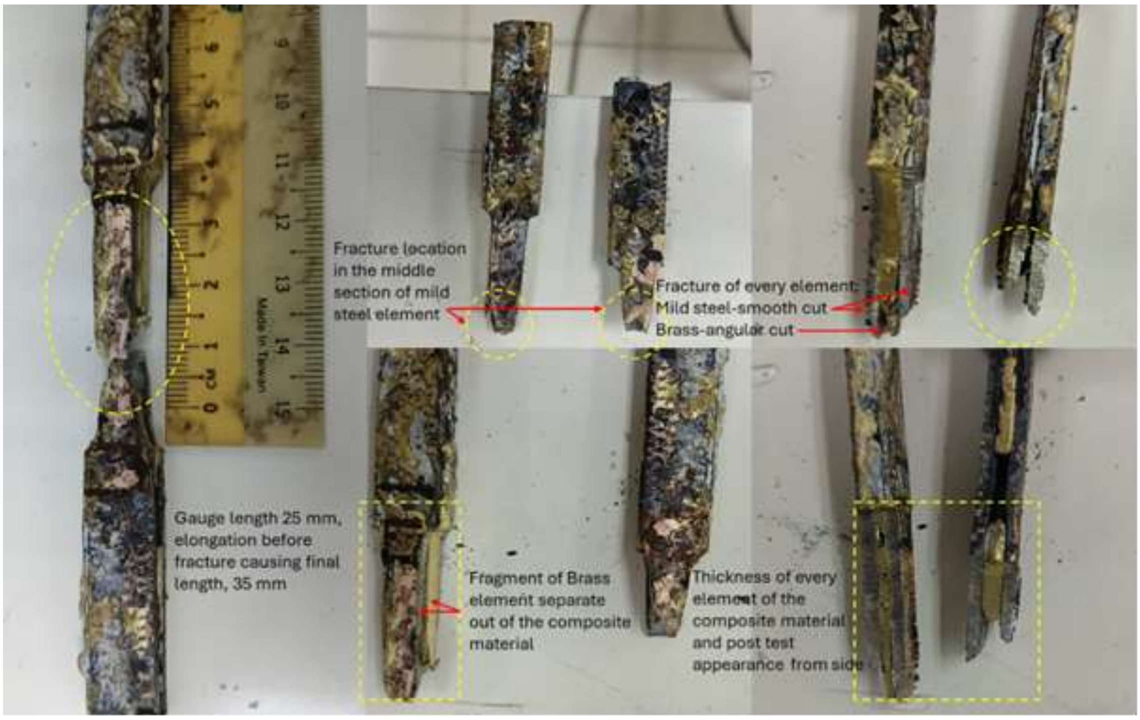

Figure 8: Failure modes of metal composite material (M.S.Brass) test specimen

Figure 8 shows the fractured specimen of M.S.Brass after tensile testing. The failure pattern observed combines both ductile and brittle characteristics due to the hybrid nature of the constituent materials. As one piece of material, necking can still be observed on the M.S.Brass specimen, indicating some plastic deformation before fracture, although less pronounced compared to the M.Steel specimen. However, when analysed separately, fracture on brass components is within minimal deformation, while fracture on mild steel components exhibits larger deformation. The fracture surface shows a mixed-mode failure, influenced by the interaction between the ductile mild steel layers and the brittle brass core. This composite structure results in a unique failure behaviour where the mild steel contributes to ductility while the brass core imposes brittle characteristics within the fractured region. In general, the failure modes of the M.S.Brass specimen coincided with tensile property results (Table 1), stress versus strain curve (Figure 4) and tensile strain comparison chart (Figure 5).

4.0 Conclusion

This study examined the mechanical properties of brass-infused mild steel, inspired by Quranic metallurgical insights, to assess its viability as a metal matrix composite material. The results showed that the composite achieved the lowest tensile strength between pure brass and mild steel, but with significantly improved ductility and strain capacity. Failure analysis revealed a mix of ductile and brittle behaviour, suggesting the need for enhanced bonding techniques. The findings indicate that this composite has promising applications in engineering fields requiring high strain and flexibility, such as in the space industry, military armour, ballistic and protective structures and the automotive industry. Future research should focus primarily on translating copper alloy in Quranic verses to bronze and applying it similarly as implemented in this study. Then the next focus is on controlling the metal smelting environment to prevent the formation of oxides due to high temperature, as occurred in this study with zinc. After that, there is also potential in optimising processing parameters to enhance interfacial bonding and mitigate failure modes observed in this study. Finally, an extensive study should consider conducting additional mechanical tests as well as material characterisation through SEM or a metallurgical microscope to further refine its performance and potential industrial applications.

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Author Contributions

Muhamad Soffi Manda: Conceptualisation, Methodology and Data Acquisition; **Nor Shaufina Md Jaafar**: Data Curation, Writing-Original Draft Preparation and Validation; **Rina Fakhizan Mohd Sukri**: Validation, Writing-Reviewing and Editing.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by any other journal. All authors have reviewed and approved the manuscript, consent to its submission, and declare that there are no conflicts of interest.

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