

Experimental Investigation of Constituent Materials for Multilayered Impact-Resistant Panels: Fiber-Reinforced Ceramic, Shape Memory Alloy, and Titanium Alloy Lattice Structures

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Lattice Structures

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ABSTRACT

This experimental study investigates the mechanical performance and energy absorption characteristics of materials intended for use in a newly developed multi-layered impact-resistant panel. The proposed lightweight structure integrates a fiber-reinforced ceramic (FRC), a nickel-titanium shape memory alloy (SMA), and additively manufactured Ti-6Al-4V lattice structures with uniform body-centered cubic (UBCC) and vertical strut (UBCCz) configurations. Each constituent material was fabricated, heat-treated under controlled conditions, and mechanically tested to evaluate its suitability for impact-resistant applications. The FRC panels exhibited a compressive strength of 50 MPa and a fracture toughness of $2.8 \text{ MPa}\cdot\text{m}^{1/2}$, confirming their effectiveness as a strike-face layer. Heat treatment of the SMA at 700°C for 30 minutes increased the energy absorption and failure strain of the specimen by 21% and 40%, respectively, albeit with a reduction in tensile strength. For the Ti-6Al-4V lattice structures, non-heat-treated samples of both the UBCC and UBCCz configurations demonstrated superior compressive properties relative to heat-treated ones. Increasing the strut diameter from 1 mm to 2 mm in the UBCCz configuration led to substantial improvements in both compressive strength and energy absorption. Numerical simulation results available in the literature and the experimental results of the multi-layered panel of the present study were observed to be in good agreement. At an impact velocity of 100 m/s, the panel effectively distributed impact energy, with 21% absorbed by the FRC layer, 28% by the SMA layer, and 50% by the titanium lattice, while the aluminum backing contributed minimally. Multilayered impact-resistant panels were physically developed based on the same sequence of material layers and are presented. Testing of the developed panel under impact loading is also suggested to observe its damage and energy absorption behavior.

1. Introduction

The use of lightweight, impact-resistant multilayered structures against dynamic loading is increasing in civil engineering, aerospace, automotive, and defense applications for the protection of critical systems. In this paper, an experimental investigation regarding the strength and energy absorption of the constituent materials of a multilayered lightweight panel consisting of FRC, SMA, 3D-printed lattice structures with UBCC and UBCCz configurations, and an aluminum sheet is presented.

1.1 Lattice Structures

The impact behavior of sandwich panels under drop weight impact tests was studied by Mines et al. [1], who demonstrated that aluminum honeycomb structures and body-centered cubic micro-lattice cores exhibit comparatively similar performance. Based on a detailed review of sandwich structures technology, Herrmann et al. [2] established the relevance of layered structure concepts in industrial and commercial applications. Queheillalt and Wadley [3] established an understanding of the mechanical response of titanium alloy lattice truss structures by characterizing the constituent materials. A comparative benchmark for the metal hexagonal honeycomb lattice performance regarding its crushing under quasi-static

and low-velocity impact through detailed theoretical and experimental analysis is presented by Mahmoud-abadi and Sadighi [4]. Rahmani et al. [5] explored the potential of Ti6Al4V-AlSi10Mg hybrid composites against impact in shielding applications. Collapse behavior and important strain-rate effects under high-speed impacts on SLM-fabricated graded Ti-6Al-4V micro-lattice structures are investigated experimentally by Xiao et al. [6]. The impact response of 3D-printed Ti-6Al-4V sandwich panels at low velocity is examined by Li et al. [7], and failure mechanisms under moderate loading rates are also discussed. Lattice structures fabricated using the SLM technique have been demonstrated by Vrána et al. [11] to have greater energy absorption capability through controlled cell length and truss diameter. McMillan et al. [15] and Brennan-Craddock et al. [16] discussed recent advances in additive manufacturing that have revolutionized the production of lightweight, complex, and dimensionally accurate structures with optimized material distribution. Manufacturing techniques of titanium-based metallic micro-lattice structures, their mechanical properties, energy absorption capabilities, strain-rate effects, and collapse behavior are extensively reviewed by Rashed et al. [19], whereas microstructural features of Ti-6Al-4V micro-lattice struts manufactured by SLM are characterized by Hasan et al. [20]. Song et al. [22] provided essential guidelines for process optimization to improve the microstructure and mechanical properties of SLM Ti-6Al-4V. Yan et al. [23] established relationships between design parameters and mechanical performance and systematically evaluated cellular lattice structures manufactured using SLM. Harris et al. [24] demonstrated that additively manufactured metallic hybrid lattice geometries outperform metallic honeycombs under impact in the intermediate velocity range (up to 100 m/s). Ullah et al. [25] investigated bio-inspired Kagome truss core structures under compression and shear loading.

Jin et al. [27] revealed that diamond lattice structures show different behavior compared to face-centered cubic (FCC) and body-centered cubic (BCC) configurations. The crushing behavior of multi-layer metal lattice panels fabricated by SLM is investigated by Li et al. [28], while Wang et al. [29] demonstrated that the fidelity and energy absorption of additively manufactured sandwich structures are enhanced by cell-size graded sandwich designs. Fadeel et al. [30] revealed that the specific energy absorption of lattice structures is primarily dependent on the lattice geometry rather than on the mass. The importance of the inclusion of vertical struts in lattice structures based on their increased compressive strength under loading is thus highlighted. The thermo-mechanical properties of different SLM lattice structures are thoroughly examined by Liu et al. [34], whereas Casata et al. [38] have systematically evaluated sample size, orientation, and laser powder bed fusion parameters that affect microstructure, defects, and mechanical performance. Increased porosity and

surface roughness in smaller strut specimens result in a reduction of the load-bearing area of up to 5.05%. An optimized configuration of the Ti-6Al-4V lattice structure was selected based on its performance, i.e., energy absorption and damage behavior under impact loading, and was 3D printed by the relevant industry for implementation.

1.2 Shape Memory Alloys

Tsoi et al. [8] reported improved damage resistance through detailed impact damage behavior studies of SMA-based composites. Meo et al. [9, 14] investigated SMA hybrid composites and reported increased toughness and energy absorption without detectable failure for aeronautical applications. Guida et al. [10], for advanced applications, studied the superelastic effects of SMA hybrid composites and reported improved mechanical performance and energy absorption under dynamic impact response. Sun et al. [13], by embedding SMAs in GF/epoxy laminates at different positions and identifying optimal placement strategies, have demonstrated improved impact performance.

To study temporal aspects of SMA performance under repeated loading for critical applications requiring multiple impact resistance, Li et al. [33] reported that the damage accumulation of SMA hybrid composite laminates is slower than that of traditional composites under low-velocity impact. The improvement is also observed to be less pronounced at higher impact energies. Ge and Wang [37] investigated Ni-Ti SMA energy-absorbing boxes under low-velocity impact and found that these have more stable crushing behavior than conventional aluminum alloys. The SMA was selected based on its performance, i.e., energy absorption and damage behavior under impact loading, as reported in the available literature, and was procured from the relevant industry for implementation.

1.3 Fiber-Reinforced Ceramics (FRC)

The damage behavior and energy absorption properties of textile-reinforced composite sandwich panels under impact loads are evaluated by Heimbs et al. [21], while hybrid sandwich panel concepts for projectile impact mitigation, demonstrating the potential of ceramic-containing configurations, are explored by Yungwirth et al. [12]. In a recent comprehensive review, Wei et al. [36] highlighted the critical importance of strain-rate-dependent materials, i.e., carbon fiber/ceramic, silicon carbide/ceramic, and oxide/ceramic matrix composites for ballistic protection. Impact performance is analyzed through impact response optimization and multi-scale damage modes. Their findings provide a valuable framework for understanding how fiber architecture and interfacial bonding strength influence impact energy dissipation mechanisms in ceramic-based systems. The FRC panel was selected based on its performance, i.e., energy absorption and damage behavior under impact loading, as reported in the available literature, and was procured from the relevant industry for implementation.

1.4 Multi-Layered Hybrid Panel

The concept of a hybrid sandwich panel for projectile impact mitigation, demonstrating that properly designed multi-material systems can outperform monolithic solutions, was pioneered and explored by Yungwirth et al. [12]. Multifunctional integration of lattice-structured impact absorbers with embedded anti-icing systems for SLM-fabricated aircraft wings was demonstrated by Ferro et al. [18]. Extensive research on sandwich structures with innovative cellular metallic cores under low-velocity impact loading was conducted, and homogenization methods for SLM cellular materials for impact performance simulation were developed by Labeas and Ptochos [26,31,32]. They developed analytical methods for determining the elastic modulus and Poisson's ratio of micro-lattice cellular structures, enabling efficient design and analysis. The effectiveness of blast-resistant multi-layer composite door panels, composed of aluminum foam serving as a primary energy absorption layer and curved steel plate connectors providing additional energy dissipation through plastic hinge rotation, against extreme loading has recently been demonstrated by Ahmad et al. [39].

1.5 Numerical Simulation of Impact Response

Complementing experimental investigations, numerical simulation plays a crucial role in understanding and optimizing impact response. Labeas and Ptochos [26] developed homogenization approaches for simulating the impact performance of SLM cellular materials. Khalid et al. [35] performed numerical investigations of 3D printed multi-layered hybrid panels under impact loading. Their work establishes baseline predictions for energy distribution across different material layers, which serve as a reference for experimental validation. The focus was on the optimization of material layering to enhance ballistic resistance. To predict the mechanical performance and energy absorption characteristics, the lightweight multilayered panel construction sequence was implemented in the same way as was done and tested numerically by Khalid et al. [35]. At an impact velocity of 100 m/s, the projectile was successfully arrested, with its velocity reducing to zero due to the complete lack of penetration. An energy absorption distribution of 21% by the fiber-reinforced ceramic, 28% by the SMA, 50% by the titanium alloy, and 0% by the aluminum layer was observed. Conversely, at a higher impact velocity of 200 m/s, the projectile perforated the panel, exiting at a residual velocity of 87 m/s. An energy absorption distribution of 1% by the FRC, 24% by the SMA, 67% by the titanium alloy, and 8% by the aluminum sheet was observed.

2. Experimental Studies

2.1 Fiber-Reinforced Ceramic (FRC) sample

FRC exhibits a low thermal expansion coefficient, low density, high temperature resistance, corrosion resis-

tance, high wear resistance, high hardness, a high melting temperature, and stable mechanical properties. The mechanical properties of the developed FRC panels are given in Table 1.

In a multilayered panel, the ceramic sheet is used at the top because of its high strength and toughness; therefore, it can absorb shock and energy during low- and medium-velocity impact events and protect the critical component. The developed FRC panel is shown in Fig. 1.

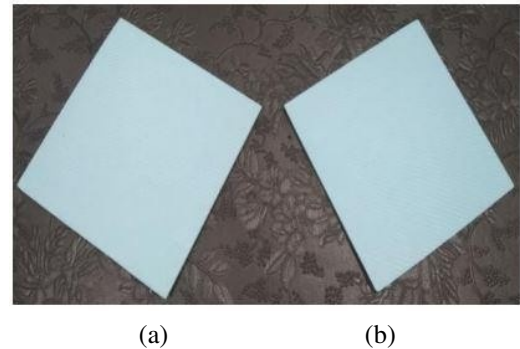


Fig. 1. Fabricated FRC Panel of 2 mm thickness

2.2 Construction of the multi-layered panel

A multi-layered panel was developed according to the following sequence: a fiber-reinforced ceramic sheet with a thickness of 2 mm at the top, followed by an SMA sheet of 1 mm, then a UBCC or UBCCz lattice structure made of titanium alloy, and finally an aluminum sheet at the bottom. The bottom surface of the fiber-reinforced ceramic sheet was bonded to the top surface of the shape memory alloy sheet, the bottom surface of the shape memory alloy sheet was bonded to the top surface of the titanium alloy lattice structure, and the bottom surface of the titanium alloy lattice structure was bonded to the top surface of the aluminum sheet using epoxy-based adhesives. The developed multi-layered panel is shown in Fig. 2.

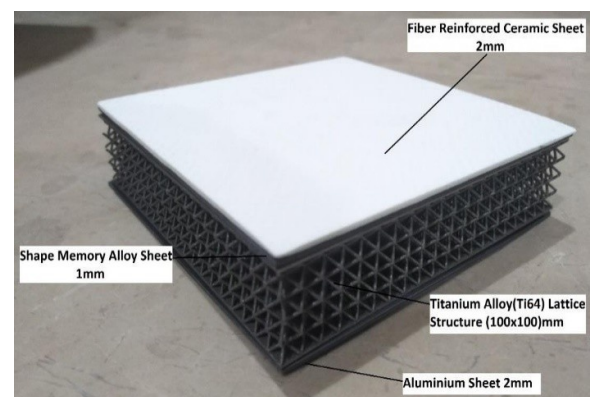


Fig. 2. Multilayered Panel

2.3 SMA sample preparation, heat treatment, and testing

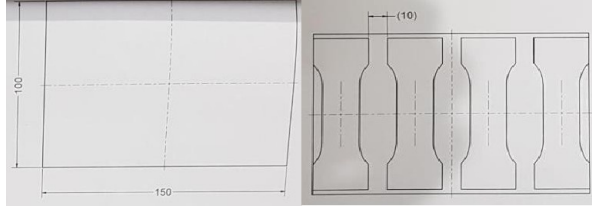
Ten tensile samples of nickel-titanium SMA were cut from two plates measuring 150 mm × 100 mm × 1 mm using EDM, in accordance with the GB/T228.1-2010 standard, to avoid residual stresses [see Fig. 3]. Eight of the ten samples were heat treated at four different

Table 1

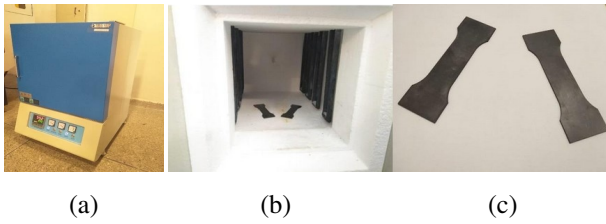
Material properties of FRC panels

Bulk Density (gcc)	Compressive Strength (MPa)	Tensile Strength (MPa)	Fracture Toughness (MPa.m ^{1/2})	Bending Strength (MPa)
1.3	50	55	2.8	67

temperatures: 500 °C for 1 hour, and 600 °C, 700 °C, and 800 °C for 30 minutes each. The effect of these heat treatments on their mechanical properties was studied.

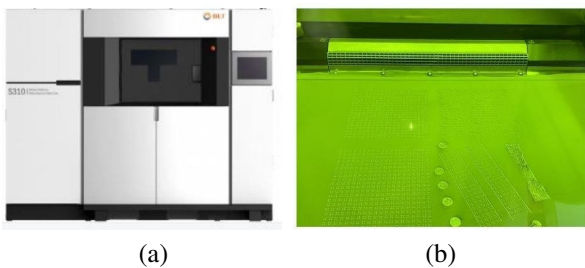
**Fig. 3.** Preparation of SMA samples

After heating, the samples were cooled in a muffle furnace [see Fig. 4(a)–(c)]. Heat treatment improved the ductility of the tensile specimens with a slight decrease in strength compared to the non-heat-treated specimens. The SMA samples were tested using a universal testing machine with a 50 kN load cell at a feed rate of 5 mm/min. Ten tests were performed on the samples, and the load-deflection results were recorded.

**Fig. 4.** (a) Muffle furnace, (b) Heating chamber, (c) Heat treatment of samples at 500~800 °C for 30 min

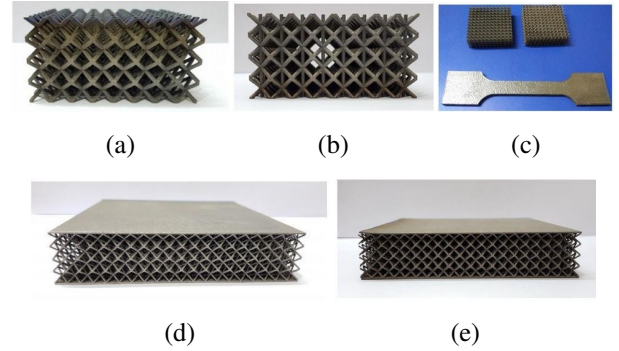
2.4 3D Printing, preparation, and heat treatment of Titanium alloy samples

Ti-6Al-4V metallic lattice structures were 3D printed using the SLM technique [see Fig. 5(a)–(b)]. The Ti-6Al-4V powder was pre-heated at 120 °C in a vacuum chamber for 4 hours to remove moisture and then allowed to cool naturally.

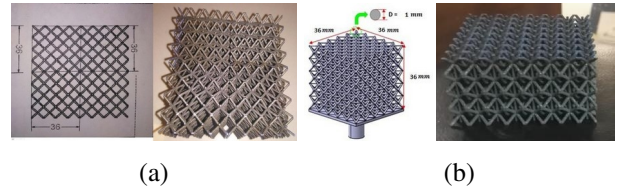
**Fig. 5.** (a) 3D printing machine, (b) sample fabrication through the SLM process

The samples were printed using the SLM machine process parameters listed in Table 2 and are shown in Fig. 6(a)–(e). After fabrication, all of the samples were heat treated at 800 °C for 80 minutes and cooled in an argon environment.

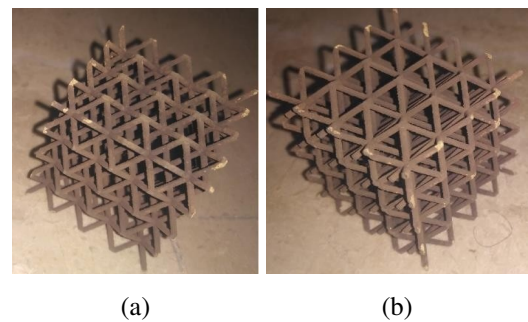
Eight samples of titanium alloy were cut into four identical parts using wire electrical discharge machining

**Fig. 6.** Fabrication of samples: (a) UBCC-z lattice structures, (b) UBCC lattice structures, (c) Sample for tensile test, (d) Uniform BCC lattice panels, (e) Graded UBCC lattice panels

(EDM) to control residual stresses, with dimensions of 36 mm × 36 mm × 36 mm. Two of the eight specimens were heat treated at 950 °C for 1 hour in a muffle furnace, and the remaining six specimens were retained without any heat treatment. The samples developed and cut using EDM are shown in Fig. 7(a)–(b).

**Fig. 7.** (a) As-built lattice structure sample produced by SLM; (b) lattice structure sample cut by wire EDM

Heat-treated samples of the UBCC and UBCCz configurations are shown in Fig. 8(a)–(b).

**Fig. 8.** Heat-treated samples of configuration: (a) UBCC, (b) UBCCz

2.4.1 Compression testing of Titanium alloy samples

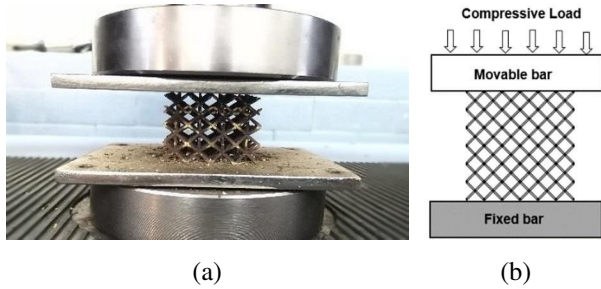
To perform compression testing, the lattice samples of size 36 mm × 36 mm × 36 mm were manufactured using SLM. Strut diameters of 1 mm, 1.5 mm, and 2 mm for the single unit cell were selected, whereas the unit cell dimensions were kept at 6 mm × 6 mm × 6 mm (see Fig. 7(b)). Compression tests on the lattice samples were performed using a universal testing machine at a constant feed rate of 5 mm/min with 50 kN and 300 kN load cells, and the load-deformation results

Table 2

SLM machine process parameters

Laser Power	Layer Thickness	Scanning Speed	Plate Temperature	Size of spot	Powder particle size
280 W	60 μm	1.25 m s^{-1}	25 $^{\circ}\text{C}$	100 μm	40 μm

were recorded (see Fig. 9(a)–(b)). Heat-treated and non-heat-treated lattice samples of the UBCC and UBCCz configurations with a strut diameter of 1 mm were tested to study the effect of heat treatment on their mechanical strength and energy absorption.

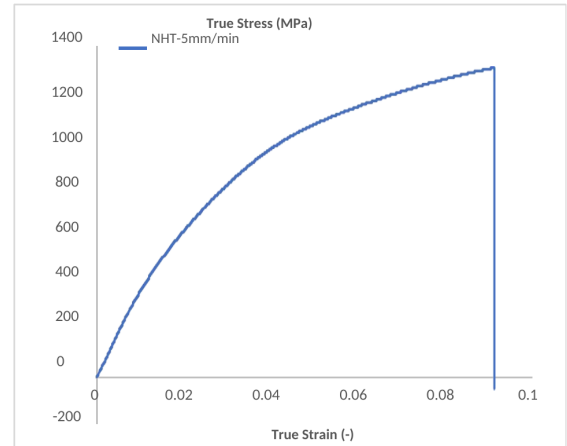
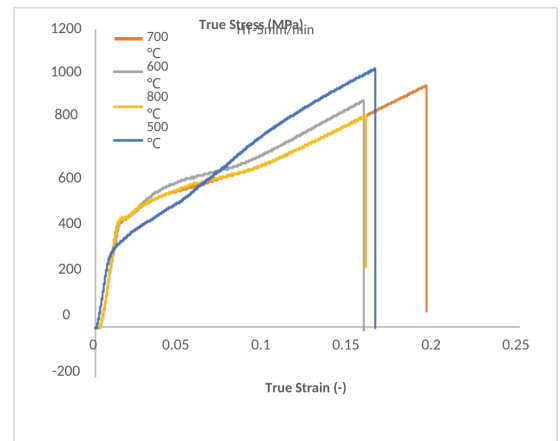
**Fig. 9.** (a) Compression test setup, (b) Test schematic

3. Results and Discussion

3.1 Tensile test results of SMA samples

The mechanical strength and energy absorption characteristics of a nickel-titanium shape memory alloy (SMA) were experimentally investigated for both heat-treated and non-heat-treated specimens. A maximum failure strain of 0.21 was recorded at 700 $^{\circ}\text{C}$, whereas a maximum tensile stress of 881 MPa was observed at 500 $^{\circ}\text{C}$. At 800 $^{\circ}\text{C}$, prolonged heat treatment cycles resulted in a reduction in specimen strength. The heat treatment protocol was designed to identify the optimal thermal cycle for the SMA intended for use in impact-resistant multilayered panels. Heat-treated samples exhibited increased energy absorption. In contrast, the tensile strength showed a slight decrease, accompanied by a marked enhancement in deformation and ductility at elevated temperatures. The tensile testing outcomes for both heat-treated and non-heat-treated specimens are summarized in Table 3.

When the samples were heat treated at 500 $^{\circ}\text{C}$ for 1 hour, the energy absorption capability was observed to improve by 14% compared to that of the non-heat-treated samples. Similarly, for heat treatment at 600 $^{\circ}\text{C}$, 700 $^{\circ}\text{C}$, and 800 $^{\circ}\text{C}$ for 30 minutes, improvements of 8%, 21%, and 6% in energy absorption were observed, respectively. For heat treatment at 500 $^{\circ}\text{C}$ for 1 hour and at 600 $^{\circ}\text{C}$, 700 $^{\circ}\text{C}$, and 800 $^{\circ}\text{C}$ for 30 minutes, failure strain was observed to increase by 33%, 30%, 40%, and 30%, respectively, whereas ultimate tensile strength was observed to decrease by 15%, 21%, 20%, and 24%, respectively, compared to those of the non-heat-treated specimens. Results for the non-heat-treated and heat-treated SMA samples are plotted in Fig. 10 and Fig. 11, respectively.

**Fig. 10.** True stress vs true strain behavior of NHT SMA specimen**Fig. 11.** True stress vs true strain behavior of HT SMA specimens at 500 $^{\circ}\text{C}$ for 1 hour and at 600 $^{\circ}\text{C}$, 700 $^{\circ}\text{C}$, and 800 $^{\circ}\text{C}$ for 30 min at a feed rate of 5 mm/min.

3.2 Tensile test results of non-heat-treated titanium alloy samples

Tensile tests were performed on non-heat-treated titanium alloy samples at feed rates of 5 mm/min and 20 mm/min. The tensile strength (max stress), max strain, and energy absorbed were observed to increase by 2.5%, 17.55%, and 9%, respectively, at a feed rate of 5 mm/min compared to those at the feed rate of 20 mm/min. The maximum elongation produced in the gage section was observed to be the same for both feed rates. Overall, it was concluded that a slower feed rate of 5 mm/min is better for mechanical strength and energy absorption capabilities. The tensile test results are summarized in Table 4. The results of engineering stress versus engineering strain, true stress versus true strain, and force versus displacement are plotted in Fig. 12(a)–(c), respectively.

Table 3

Tensile test results of heat-treated and non-heat-treated SMA samples

Sample	Max. Stress (MPa)	Failure Strain (-)	True Stress (MPa)	True Strain (-)	Energy Absorbed (J)	% increase in Failure Strain	% increase in Energy Absorbed
NHT	1193.45	0.09	1307.48	0.09	157.00	-	-
HT at 500 °C	881.01	0.18	1039.10	0.16	208.00	33	14
HT at 600 °C	777.69	0.17	910.70	0.15	187.00	30	8
HT at 700 °C	798.95	0.21	970.85	0.19	241.00	40	21
HT at 800 °C	723.67	0.17	848.46	0.15	180.00	30	6

Table 4

Tensile testing results of Ti-6Al-4V

Feed Rate (mm/min)	Max. Stress (N/mm ²)	Max. Strain (%)	Max. Force (N)	Max Disp (mm)	True Stress (N/mm ²)	True Strain (%)	Energy Absorbed (J)
5	964.03	17.58	19280.7	5.27	16291.26	2.92	74
20	917.66	15.19	18353.28	4.55	12931.23	2.78	67.5

3.3 Compression test results of Titanium alloy lattice structure samples

The energy-absorbing capabilities and deformation behavior of the UBCC and UBCCz lattice structures were evaluated through compression testing. It was observed that heat treatment, lattice configuration, and strut diameter affect the performance of the lattice structures. The results are summarized in Table 5 and are discussed in the following sections.

3.3.1 Compressive strength and energy absorption capability of heat-treated versus non-heat-treated UBCC and UBCCz samples of the same strut diameter

For UBCC and UBCCz lattice structure configurations with a strut diameter of 1 mm that were heat treated at 950 °C for 1 hour, the ultimate compressive strength, strain (%), and energy absorption were observed to decrease by 26%, 84%, and 93%, respectively, for the UBCC configuration, and by 6%, 71%, and 74%, respectively, for the UBCCz configuration, compared to those of the non-heat-treated specimens (see Fig. 13 and Fig. 14). Overall, the compressive strength and energy absorption performance of the heat-treated UBCCz samples with the same strut diameter of 1 mm were observed to be higher than those of the UBCC samples.

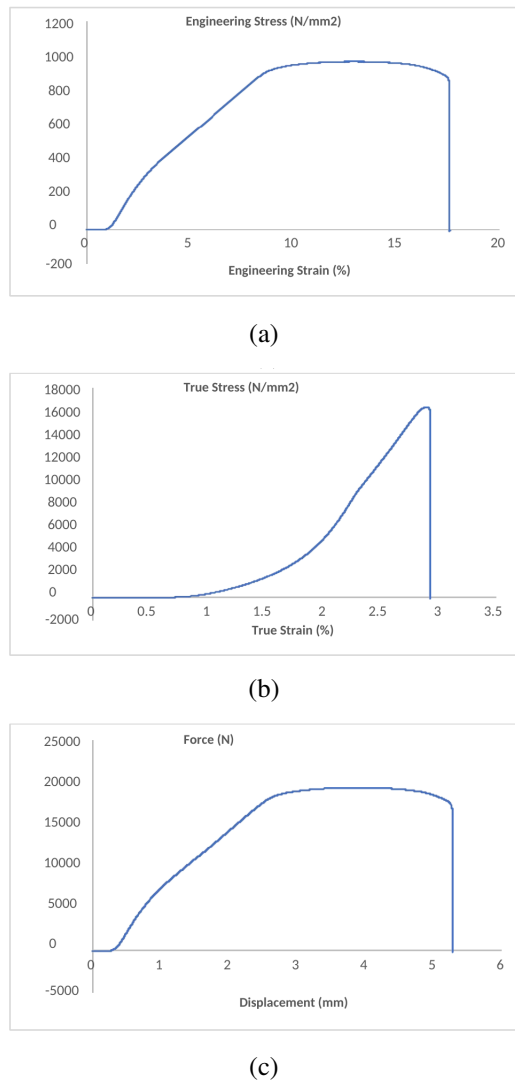


Fig. 12. Stress–strain behavior of non-heat-treated titanium alloy samples under tensile loading: (a) Engineering stress vs engineering strain, (b) True stress vs true strain, (c) Force vs displacement

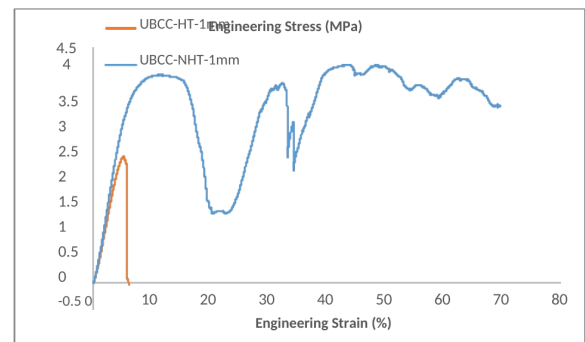


Fig. 13. Stress vs strain behavior of UBCC HT and NHT lattice structures with a strut diameter of 1 mm

Table 5

Mechanical strength and energy absorption results under compression testing of titanium alloy samples of the UBCC and UBCCz configurations with different strut diameters

Sample	Max. Stress (MPa)	Failure Strain (%)	True Stress (MPa)	True Strain (%)	Energy Absorbed (J)
UBCC-1mm-HT	2.41	6.03	0.09	7.56	3.76
UBCC-1mm-NHT	4.16	69.45	0.11	6.86	106.53
UBCCz-1mm-HT	10.46	3.27	0.06	6.98	6.32
UBCCz-1mm-NHT	12.01	20.41	0.21	6.76	43.26
UBCC-1.5-mm-NHT	38.64	74.35	0.31	7.67	423.00
UBCCz-1.5-mm-NHT	37.87	12.25	0.06	8.14	156.00
UBCC-2mm-NHT	42.50	15.53	-	-	17400.00
UBCCz-2mm-NHT	85.50	14.95	-	-	40700.00

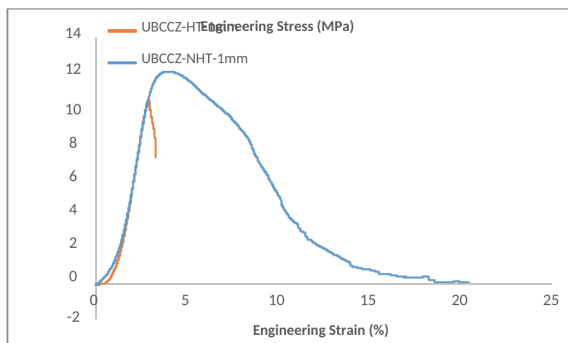


Fig. 14. Stress–strain behavior of UBCCz HT and NHT lattice structures with a strut diameter of 1 mm

3.3.2 Comparison of compressive strength and energy absorption capability of non-heat-treated UBCC and UBCCz samples of different strut diameters

With an increase in the strut diameter of non-heat-treated UBCC and UBCCz lattice structures, the compressive strength and energy absorption of both configurations were observed to increase. This is attributed to the densification of the lattice structures. With the strut diameter increased to 1.5 mm, the UBCC lattice structure demonstrated 63% more energy absorption capability than the uniform UBCCz lattice structure, with almost the same compressive strength [Fig. 15]. The UBCCz lattice structure with a strut diameter of 2 mm demonstrated a 50% increase in compressive strength and a 57% increase in energy absorption compared to the UBCC lattice structure, as shown in [Fig. 16].

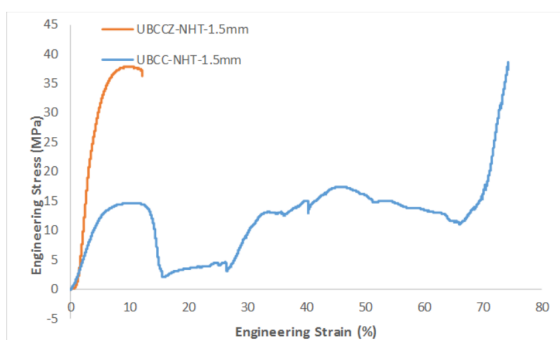


Fig. 15. Stress–strain behavior of UBCC-1.5mm and UBCCz-1.5mm NHT lattice structure specimens

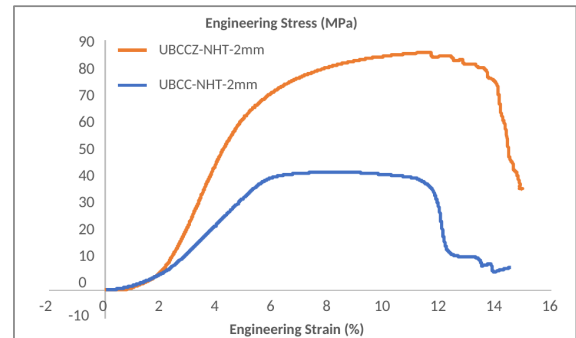


Fig. 16. Stress–strain behavior of UBCC-2mm and UBCCz-2mm NHT lattice structure specimens

4. Conclusions

The mechanical strength and energy absorbing capabilities of fiber-reinforced ceramics, shape memory alloy, and titanium alloy were investigated experimentally, and the following conclusions are drawn.

1. A fiber-reinforced ceramic sheet is recommended to be used at the top because of its high strength and toughness; therefore, it can absorb shock and energy during low- and medium-velocity impact events and protect the critical component.
2. For the SMA samples, the energy absorption and failure strain under heat treatment at 500 °C for 1 hour and at 600 °C, 700 °C, and 800 °C for 30 minutes increased by 14%, 8%, 21%, and 6% for energy absorption, and by 33%, 30%, 40%, and 30% for failure strain, whereas tensile strength decreased by 15%, 21%, 20%, and 24% as a result of the increased ductility of the material at high temperatures for extended periods, compared to that of the non-heat-treated samples.
3. For non-heat-treated titanium alloy samples subjected to tensile tests, the maximum strength, maximum strain, and energy absorption were observed to increase by 2.5%, 17.55%, and 9%, respectively, at the lower feed rate of 5 mm/min, which was concluded to be better than that at the feed rate of 20 mm/min.
4. It is concluded that for UBCC and UBCCz lattice structures with the same strut diameter, the ultimate compressive strength, strain, and energy absorption

capabilities of non-heat-treated samples are better than those of the heat-treated samples. Overall, the ultimate compressive strength and energy absorption performance of the heat-treated UBCCz samples with the same strut diameter of 1 mm were observed to be higher than those of the UBCC samples.

5. By increasing the strut diameter of non-heat-treated UBCC and UBCCz lattice structures, the compressive strength and energy absorption of both configurations were observed to increase due to the densification of the lattice structures.
6. For a strut diameter of 2 mm, the UBCCz lattice structure showed an increase in compressive strength of 50% and an increase in energy absorption of 57% compared to those of the UBCC lattice structure.
7. The focus was on the optimization of material layering to enhance ballistic resistance. At an impact velocity of 100 m/s, the projectile was successfully arrested, with its velocity reducing to zero due to the complete lack of penetration. An energy absorption distribution of 21% by the fiber-reinforced ceramic, 28% by the SMA, 50% by the titanium alloy, and 0% by the aluminum layer was observed. Conversely, at a higher impact velocity of 200 m/s, the projectile perforated the panel, exiting at a residual velocity of 87 m/s. An energy absorption distribution of 1% by the FRC, 24% by the SMA, 67% by the titanium alloy, and 8% by the aluminum sheet was observed.
8. The focus was on the optimization of material layering to enhance ballistic resistance. To predict the mechanical performance and energy absorption characteristics, the lightweight multilayered panel construction sequence was implemented in the same way as was done numerically by Khalid et al. [35]. Future impact testing of the panel is suggested to observe its performance.

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