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RESEARCH ARTICLE

Design and production of new type reinforced U-profile composite panels

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ABSTRACT

In aircraft design, factors such as fuel efficiency, lightness and durability are critical due to the effect of various loads. Therefore, the use of "U" profile beams, which are stronger in terms of strength, provides versatile advantages. In this study, a reinforced composite panel was designed and fabricated by adding support beams to the "U" profiles to maintain the safety and integrity of aircraft structures. Glass fiber and epoxy resin were employed in the composite production process. The vacuum infusion method was employed for composite production, with molds specifically designed for the "U" profile and "I" support beams. Following production, the compatibility of the "U" profile, "I" support beam and sub-composite base forming the composite panel was evaluated. It was determined that the produced "I" support beam constituted only 18.8% by weight of the composite panel.

Keywords: Fiber reinforced, Vacuum infusion, U-profile, Stiffened composites, Glass

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1. INTRODUCTION

The utilization of composite materials in the aviation industry has witnessed a notable surge in recent years, driven by their lightweight nature, durability and performance-enhancing properties. These materials are being employed with greater frequency in the design and manufacture of critical structural components, including aircraft fuselages and wings. Reinforced composite panels serve as the fundamental structural components that constitute the primary framework of aircraft. The reinforced panel exerts a significant influence on the stability of the body and its bearing capacity after buckling. Consequently, it is of paramount importance to examine these structures in terms of strength.

A number of studies have been conducted in the literature examining the mechanical behaviors of U-profile composite panels and similar structures under different loading conditions. In one such study, Elaldi and Çolak determined the buckling and post-buckling behavior of hat-stiffened composite panels under compressive loading [1]. The buckling and post-buckling behaviors are of great importance for maintaining structural integrity. Subsequently, Feng et al. conducted impact tests on reinforced composite panels at various damage locations to investigate the effects of damage on structural behavior [2]. Furthermore, Kurşun et al. conducted low-velocity impact tests on aluminum sandwich composite plates, which were manufactured using a low-density polyethylene core between two aluminum sheets [3]. The effect of impactor

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geometry on impact performance was examined both experimentally and numerically. The aforementioned studies have demonstrated that the impact and buckling behaviors of composite structures have a significant effect on their durability. In a study published Han et al. conducted experimental and numerical investigations into the axial crushing behavior of CFRP U-profile beams subjected to axial compressive loading [4]. This study provides crucial insights into the performance of U-profiles under axial loads. A similar approach was employed by Alkhatib et al., who examined the energy absorption capacity and crushing behavior of composite corrugated pipes under quasi-static axial shear crushing loading [5]. These investigations have yielded significant findings that are aimed at enhancing the energy absorption capacities of composite structures. Kumar et al. conducted axial compression tests to determine the pre-buckling and post-buckling behaviors of bi-layered composite panels reinforced with evenly spaced hat-stiffened profiles [6]. While these studies examine methods to enhance the buckling resistance of structures, Sun et al. conducted experimental investigations to examine the buckling behavior of U-profile reinforced composite specimens under axial compressive loading [7]. The findings of this research demonstrate the efficacy of practical methods for enhancing the structural durability of U-profiles. Ataabadi et al. conducted an experimental and numerical investigation into the dynamic axial crushing response of circular pipes made of unidirectional CFRP [8]. This study is of significant importance in order to gain an understanding of the behavior of composite structures under dynamic loads. In a recent study, Feng et al. conducted experimental and theoretical analyses of the shear performance of composite panels reinforced with I-profiles [9]. The findings revealed the effects of different profile shapes on structural performance. In a related study, Li et al. examined the static and fatigue behaviour of U-profile panels subjected to four-point bending loads, both experimentally and numerically. This research is of significant importance in the understanding of the long-term durability of composite panels [10]. Liu and Xu conducted impact and post-impact compression tests on composite specimens reinforced with single hat profiles, either filled or unfilled [11]. The objective was to analyse the effects of the filler material on buckling failure load and impact damage tolerance. This study demonstrates the impact of filler materials on structural durability. Hou et al. conducted an investigation into the low-velocity impact and post-impact crushing behaviours of reinforced CFRP panels, both experimentally and numerically [12]. Kumar et al. in their research propose a computationally efficient methodology using the Constrained Variable Asymptotic Method (C-VAM) for nonlinear torsion analysis in a hat beam panel with delamination defects [13]. In a study, Ahmadi and Rahimi investigate the behavior of grid reinforced composite panel (GSCP) subjected to transverse loading through analytical and experimental approach [14]. Wu et al. In their article, the compressive buckling and post-buckling behavior of J-type composite hardened panels before and after impact load were examined with theoretical, numerical and experimental methods [15]. Suriani et al have created a review article and accordingly compiles the review on delamination and common manufacturing defects in natural fiber reinforced hybrid polymer composites that affect the performance of the composites [16]. Kong et al have two purposes in their writing. The first is to see and understand the detailed buckling process in the post-buckling phase of stiffened panels subjected to in-plane compressive loading, especially the interactions between material nonlinearity and geometric nonlinearity. The second is to verify the similarity criteria of the design of different sizes of stiffened panels with the same torsional modes and proportional ultimate strength [17].

The aim of Kolanu et al. work is to experimentally investigate the stability behavior and damage properties of carbon fiber reinforced polymer (CFRP) composite panels with secondary bonded blade stiffeners under pressure [18]. van Dooren et al. Two aerospace thermoplastic composite toughened panels were analyzed and tested to investigate buckling behavior, surface beam separation and final damage mode [19].

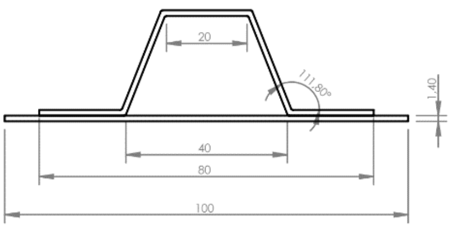
The findings of this research are of significant importance in the context of maintaining structural integrity following impacts.Nevertheless, the strength and durability of these structural components must be enhanced continuously, particularly in the context of variable loads and flight conditions.

In general, different types of reinforced composite profiles have been compared in the literature. This study compared unsupported samples with supported samples and clearly demonstrated the difference. In this study, unlike the literature, new types of composite panels have been developed by adding "I" support beams to U-profile composite panels. In the production of composite panels, the appropriate dimensions for the U-profile and support beam were first determined, and then a three-dimensional design was created. Subsequently, molds were manufactured to the specified dimensions, and panel components were produced via the vacuum infusion method. The combination of the produced parts and the effect of the added support profile on the weight were discussed as a result.

2. MATERIALS AND METHODS

2.1 Design of reinforced U-profile composites

The initial phase of the study involved the determination of the dimensions of the U-profile composite panel and the creation of drawings. To this end, an unsupported U-profile composite panel design was initially created. Subsequently, an I-support beam was designed and its dimensions were determined to be placed within the U-profile for reinforcement purposes. The dimensions of supported and unsupported U-profile composite panel**s** are presented in Figure 1-2.



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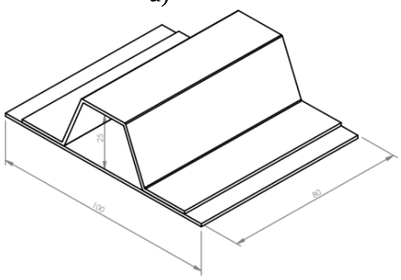

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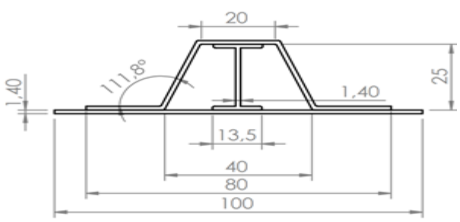
Figure1. Specimen without support a) Front b) Three-dimensional view of the model



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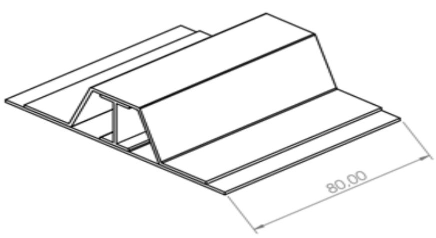

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Figure 2. Specimen with support a) Front b) Three-dimensional view of the model

The study encompassed the placement of I-profile support beams within U-profile composites for reinforcement purposes. In order to facilitate the production of these composites using the vacuum infusion method, the requisite mold designs were created in three dimensions and manufactured using steel material on a computer numerical control (CNC) machine. The use of metal molds was intended to ensure uniform temperature transfer to the composite specimen during the vacuum infusion process. The aforementioned mold design is depicted in Figure 3. A single-piece mold was deemed the optimal choice for the production of U-section composites. During the production of the I-support beam, the dimensions of the mold cavities were designed to be adjustable in order to achieve the desired thickness. Consequently, a multi-piece mold design was created for the I-support (Figure 4).

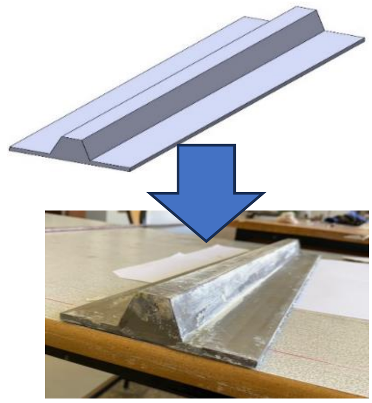


Figure 3. Designed U-profile mold and its produced form

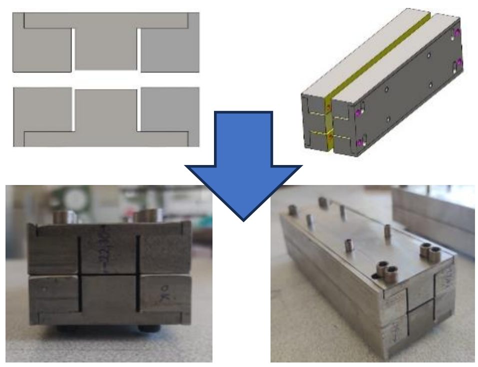


Figure 4. Designed I-profile mold and its produced form

2.2 Production of reinforced U-profile composites

The scope of the study encompassed the production of both U- and I-profile composites via the vacuum infusion method. The composite was manufactured using twill 2x2 weave type glass fiber woven fabrics as the fiber material. The thickness of the glass fiber layer is approximately 0.29 mm. The matrix material comprised MGSH160 resin and MGSL160 hardener. Both materials are commercial products obtained from Dost Kimya A.Ş., Istanbul, Turkey. The production process was conducted on a temperature-controlled vacuum infusion bench. In the production of composite materials, a release film is first applied to the surface of the bench in order to facilitate the subsequent removal of the fiber fabrics. Sub-sequently, in order to ensure the secure attachment of the release layer to the bench, the perimeter of the layer is affixed with double-sided tape. The molds were positioned at appropriate intervals in accordance with the specifications depicted in Figure 5. As illustrated in Figure 6, the glass fibers were cut to the specified dimensions and stacked according to the designed model. In order to facilitate the separation of the composite plate produced following the manufactung process from the consumables, such as the flow mesh and vacuum nylon, which were applied on top, a peel ply was applied over these fabrics.

a) b)

Figure 5. a) Use of release film and tape in composite production b) Arrangement of U-profile molds

Figure 6. Use of glass fiber and peel ply in composite production

In a vacuum environment, a green vacuum infusion mesh was positioned on the surface of the peel ply, allowing the resin to flow freely and wet the entire fabric. To prevent the peel ply and infusion mesh from being displaced by the vacuum, they were fixed to the release layer using paper tape. Furthermore, spiral hoses and connection elements were placed on both sides of the fabric in order to ensure the homogeneous distribution of epoxy resin on the fabric surface and to wet the entire surface, as illustrated in Figure 7. This process allowed for the absorption of the resin and the evacuation of any excess. Albayrak, M., et al [20], Erdem, S.,et al [21] and Bozkurt,İ.[22] They produced composites using the vacuum infusion method in stores and produced them using lightweight methods with low temperatures.

In the final stage, vacuum nylon was applied over the double-sided tape that held the bench and the release layer together. Vacuum hoses were then connected to the aforementioned connection elements in the spiral hoses. Once the vacuum hose on the side where the resin would be absorbed had been secured with a clamp, it was left under vacuum for a period of 15 minutes. The vacuum pressure gauge was monitored to ascertain the absence of any air leaks. Once the sealing checks had been completed, the resin-hardener mixture was prepared. In the production phase, woven glass fiber with an areal weight of 300 g/m² and epoxy resin with a hardener mixture ratio of 100/20 by weight were utilised. While the specimens were subjected to vacuum, the vacuum pump was activated and the vacuum hose on the side where the resin would be absorbed was immersed in the mixture without allowing air to enter. Subsequently, the homogeneous mixture was impregnated into the woven glass fiber fabrics under vacuum, and then cured at 100°C for a period of two hours.

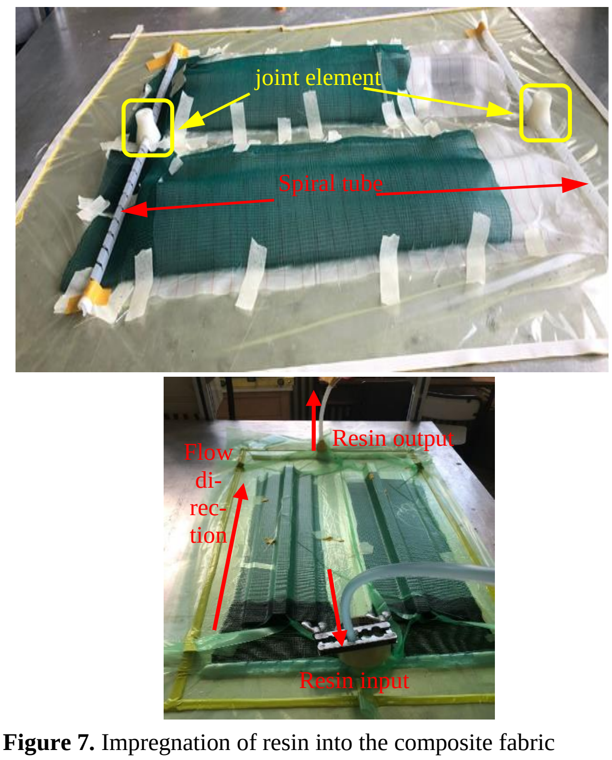


Figure 7. Impregnation of resin into the composite fabric

3. RESULTS AND DISCUSSION

This study has examined the production, cutting, and assembly processes of composite specimens produced using the vacuum infusion technique in great detail. After the curing process, the specimens removed from the mold were cut to a length of 80 mm using a waterjet cutting machine in order to prepare them for assembly. The waterjet cutting technique ensured precise obtaining of the specimens in the desired dimensions. During the cutting process, meticulous work was carried out to maintain the structural integrity of the materials. In the assembly process, I-profile composite beams were adhered inside the U-profile composites as support beams (Figure 8).

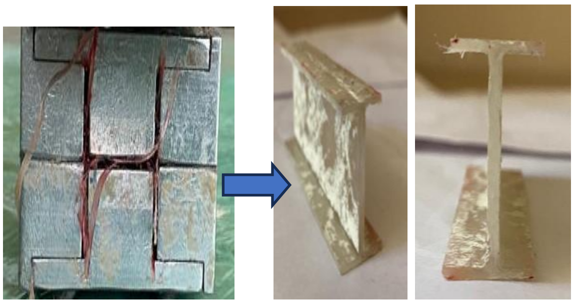
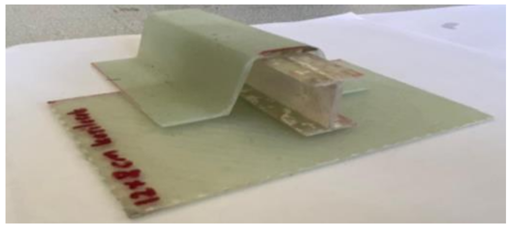


Figure 8. The wetted glass fiber layers inside the mold prepared for the support beam and the produced support beam.

It is of critical importance to ensure a consistent bonding thickness in order to maintain the quality and structural integrity of the assembly. In this study, the bonding thickness was set to 0.15 mm. To achieve a standard bonding thickness, a specialized bonding mold was employed (Figure 9). The mold ensured uniformity of the total bonding thickness, thus facilitating accurate adjustment of specimen height and preventing any axis misalignments or symmetry irregularities that could occur during bonding. Prior to the assembly stage, composite specimens produced using the vacuum infusion method were visually inspected to identify any manufacturing defects.

The specimens obtained exhibited symmetrical geometry and were observed to be axial in the loading direction. Following visual inspection, the bonding process was initiated, and the specimens were left in the mold for 24 hours to allow the adhesive to fully cure.

Figure 9. Height adjustable mold used to bond parts of a reinforced U-profile beam to each other



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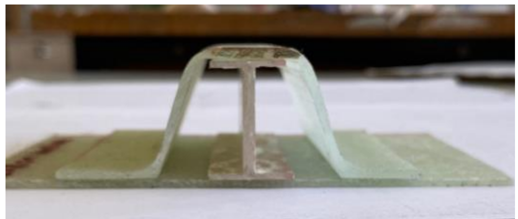

b)

Figure 10. a) Reinforced U-profile specimen, b) Cross-sectional view of the reinforced U-profile specimen

4. CONCLUSION

This study successfully demonstrated the design and production of a novel U-profile composite panel reinforced using the vacuum infusion technique. The findings revealed in detail the advantages and difficulties encountered by this method in the production of composite materials.

- The proposed model is straightforward to manufacture and assemble. The vacuum infusion method has emerged as an effective technique for the production of composite materials. Consequently, the components are joined together with complete contact, eliminating any gaps. This condition has been a critical factor in maintaining the quality of the assembly and structural integrity, as ensured by maintaining a constant bonding thickness of 0.15 mm.
- The resulting reinforced U-profile composite panels exhibit high structural integrity and symmetrical geometry and may be considered an important step in improving the performance of composite materials used in the aviation industry. The additional weight (18.8%) associated with the incorporation of the support beam may be offset by the strength gain.
- However, in order to reveal this, it is necessary to prepare specimens for multiple production, impact and compression tests, and to measure their performance in terms of specific gravity. It is also recommended that future studies examine different material combinations and infusion methods. Nevertheless, the application of numerical analysis and the evaluation of the model obtained in

this study will facilitate a more comprehensive understanding of the performance and durability of reinforced composite structures. Such research will contribute to the development of safer, lighter and more durable structural components in the aviation industry.

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REFERENCES

1. F. Elaldi and L. Colak, "Buckling and Post-buckling Behavior of Compression Loaded Composite Panels with Hat Stiffeners," J. Reinf. Plast. Compos., vol. 28, no. 20, pp. 2501–2509, Sep. 2008, doi: 10.1177/0731684408092394.

2. Y. Feng, H. Zhang, X. Tan, Y. He, T. An, and J. Zheng, "Effect of impact damage positions on the buckling and post-buckling behaviors of stiffened composite panel," Compos. Struct., vol. 155, pp. 184–196, 2016, doi: https://doi.org/10.1016/j.compstruct.2016.08.012.

3. A. Kurşun, M. Şenel, H. M. Enginsoy, and E. Bayraktar, "Effect of impactor shapes on the low velocity impact damage of sandwich composite plate: Experimental study and modelling," Compos. Part B Eng., vol. 86, pp. 143–151, 2016, doi: https://doi.org/10.1016/j.compositesb.2015.09.032.

4. X. Han, S. Hou, L. Ying, W. Hou, and H. Aliyev, "On the fracture behaviour of adhesively bonded CFRP hat-shaped thin-walled beam under axial crushing load: An experimental and modelling study," Compos. Struct., vol. 215, pp. 258–265, 2019, doi: https://doi.org/10.1016/j.compstruct.2019.01.075.

5. F. Alkhatib, E. Mahdi, and A. Dean, "Crushing response of CFRP and KFRP composite corrugated tubes to quasi-static slipping axial loading: Experimental investigation and numerical simulation," Compos. Struct., vol. 246, p. 112370, 2020, doi: https://doi.org/10.1016/j.compstruct.2020.112370.

6. S. Kumar, R. Kumar, and S. Mandal, "Experimental and FE analysis for the buckling behavior of hat-stiffened panels under edge compressive loading," Sādhanā, vol. 45, no. 1, p. 130, 2020, doi: 10.1007/s12046-020-01364-8.

7. Z. Sun et al., "Prediction of compression buckling load and buckling mode of hat-stiffened panels using artificial neural network," Eng. Struct., vol. 242, p. 112275, 2021, doi: https://doi.org/10.1016/j.engstruct.2021.112275.

8. P. B. Ataabadi, D. Karagiozova, and M. Alves, "Finite element modeling of crushing of CFRP cylindrical tubes under low-velocity axial impact," Compos. Struct., vol. 280, p. 114902, 2022, doi: https://doi.org/10.1016/j.compstruct.2021.114902.

9. Y. Feng, S. Liu, T. Zhang, and S. Jiao, "Experimental and theoretical investigation on the shear performance of stiffened composite panel with I-shaped stiffeners," Compos. Struct., vol. 284, p. 115234, 2022, doi: https://doi.org/10.1016/j.compstruct.2022.115234.

10. B. Li, Y. Gong, Y. Gao, M. Hou, and L. Li, "Failure Analysis of Hat-Stringer-Stiffened Aircraft Composite Panels under Four-Point Bending Loading," Materials, vol. 15, no. 7. 2022. doi: 10.3390/ma15072430.

11. L. Liu and W. Xu, "Effects of fillers on the impact damage and compressive residual properties of single hat-stiffened composite panels," Thin-Walled Struct., vol. 180, p. 109705, 2022, doi: https://doi.org/10.1016/j.tws.2022.109705.

12. Y. Hou, J. Huang, Y. Liu, L. Meng, T. Sapanathan, and Y. Xu, "Low-velocity impact and compression after impact behaviors of rib-stiffened CFRP panels: Experimental and numerical study," Aerosp. Sci. Technol., vol. 146, p. 108948, 2024, doi: https://doi.org/10.1016/j.ast.2024.108948.

13. A. P. Kumar, J. P. Mendez, R. G. Burela, C. Bisagni, D. Harursampath and S. A. Ponnusami, "Non-linear buckling analysis of delaminated hat-stringer panels using variational asymptotic method," Compos. Struct, vol. 345, p. 118276, 2024, doi: https://doi.org/10.1016/j.compstruct.2024.118276.

14. Ahmadi H., Rahimi G., "Analytical and experimental investigation of transverse loading on grid stiffened composite panels", Composites B, v. 159 2019,p.184-198, doi:https://doi.org/10.1016/j.compstruct.2022.116339.

15. Wu Q., Hu S., Tang X., Liu X., Chen Z., Xiong J., "Compressive buckling and post-buckling behaviors of J-type composite stiffened panel before and after impact load," Compos Struct, v. 304, 2023, p. 116339, doi: https://doi.org/10.1016/j.compstruct.2022.116339.

16. Suriani M., Rapi H.Z., Ilyas R., Petru M., Sapuan S. "Delamination and manufacturing defects in natural fiber-reinforced hybrid composite: A review", Polymers, v.13, no. 8, 2021, p. 1323 doi: https://doi.org/10.3390/polym13081323.

17. Kong X., Yang Y., Gan J., Yuan T., Ao L., Wu, "Experimental and numerical investigation on the detailed buckling process of similar stiffened panels subjected to in-plane compressive load",Thin-Walled Struct, v.148, 2020, p. 106620, doi: https://doi.org/10.1016/j.tws.2020.106620.

18. Kolanu N.R., Raju G., Ramji, "Experimental and numerical studies on the buckling and post-buckling behavior of single blade-stiffened CFRP panels", Compos Struct, v.196, 2018, p. 135-154, doi: https://doi.org/10.1016/j.compstruct.2018.05.015.

19. van Dooren K.S., Tijs B., Waleson J., Bisagni C., "Skin-stringer separation in post-buckling of butt-joint stiffened thermoplastic composite panels", Compos Struct, v.304, 2023, p. 116294, doi: https://doi.org/10.1016/j.compstruct.2022.116294.

20. Albayrak, M., Kaman, MO, Bozkurt, I., "Kauçuk Ara Katmanlı Kavisli Kompozitler İçin Düşük Hızlı Darbe Davranışı Üzerindeki Geometrik Etkinin Deneysel ve Sayısal Araştırması." Appl Compos Mater,v.30 , p.507–538, 2023. doi:https://doi.org/10.1007/s10443-022-10094-5

21. Erdem, S., Kaman MO.,Gür M., "Karbon fiber epoksi kompozit levhaların burkulma sonrası davranışı." Mekanik Bilim ve Teknoloji Dergisi, v.33, 2019, p.1723-1730.

22. Bozkurt, I., Kaman, MO, Albayrak, M., "Farklı hücre tipleri için tamamen karbon fiber kompozitten üretilen sandviçlerin düşük hızlı darbe davranışları ve farklı çekirdek tipleri için sıkıştırma davranışları." Malzeme Testleri, v.*65*, no.9, p.1349-1372.