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Studies on Tensile Characteristics of Kevlar/Jute/ Syntactic Foam Hybrid Sandwich Composites

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Abstract

In this study, a structured approach combining Taguchi experimental design and analysis of variance (ANOVA) is used to investigate the effects of skin material choice, material density, and percentage of reinforcement on the tensile properties of Kelvar/jute/synthetic foam hybrid sandwich composites. By deliberately changing these variables and examining how they affect tensile strength, modulus, and other important qualities, the goal is to maximize the mechanical performance of these composites. This work gives helpful insights into the interaction of these variables and their contribution to the overall tensile behavior of the composites through a series of carefully planned experiments and statistical studies. While ANOVA aids in quantifying the importance of individual components and interactions, the Taguchi approach makes it easier to identify the ideal parameter values. Making a substantial addition to the field of materials science and engineering, this combined method provides a solid framework for improving the design and engineering of lightweight, high-strength sandwich composites with customized features.

Keywords: *Skin material, Material density, Percentage of reinforcements, Tensile properties, Kelvar/jute/synthetic foam hybrid sandwich composites, Taguchi experimental design and analysis of variance (ANOVA).*

1. Introduction

Modern materials that combine the benefits of several components or layers into a sandwich-like structure are referred to as hybrid sandwich composites. A central "core" or core material, two outside "skins" or face sheets, and an inner layer are the traditional three major layers of these composites. The core is meant to accomplish a number of things, like enhancing rigidity, providing insulation, or reducing weight, whereas the skins are meant to preserve structural integrity and safeguard the core [1-3]. Hybrid sandwich composites mix several materials, often chosen for their distinct properties and applications. These materials include things like metals, polymers, ceramics, foams, natural and artificial fibers, and more. When choosing the materials, the necessary characteristics and performance standards for the final composite are taken into consideration [4,5]. Combining materials with complimentary properties, hybrid sandwich composites can function more effectively as a whole than as a sum of its parts. For instance, combining a high-strength material with a light core can result in a composite that is both strong and light. Designers can modify the properties of hybrid sandwich composites to meet specific technical requirements. For instance, by choosing suitable materials for the skins and core and adjusting their thicknesses, the composite's stiffness, strength, thermal insulation, and acoustic qualities can be changed. Sandwich constructions' capacity to offer high strength-to-weight ratios is one of their main advantages [6-9]. Because of this, they are especially appealing in sectors where weight savings are crucial, such aerospace and automotive applications. In applications where energy absorption is crucial, like the construction of impact-resistant structures, protective gear, and vehicle crash panels, hybrid sandwich composites are frequently employed. It is possible to effectively absorb and disperse energy using the core material [10, 11]. The manufacture of sporting equipment, as well as the aerospace, marine, automotive, and construction industries, all use these composite materials. Engineers are able to meet a variety of needs and issues in a variety of industries thanks to their adaptability. Hybrid sandwich composites are made using methods like bonding, lamination, and resin infusion. The final structure's integrity is guaranteed by cutting-edge production techniques like vacuum bagging and autoclave curing. Hybrid sandwich composites have many benefits, but their design and production can be challenging since they must carefully take into account material compatibility, bonding strategies, and the avoidance of delamination or other structural problems [12-14].

Sandwich panels are often made from a variety of core materials in the world of literature, including wood, polyethylene terephthalate (PET), aluminum honeycomb, polyvinyl chloride (PVC), polystyrene, and, most significantly, syntactic foam, which has recently grown in prominence as a core material. There has been a lot of study on mechanically characterizing foams and their sandwich structures, with a focus on syntactic foam sandwich composites [15-16]. For instance, Islam et al. [14] looked into the tensile and flexural properties of sandwich composites made of foam cores and paper skins. Their research showed that adding paper skins to the syntactic foam core considerably boosted flexural strength by up to 40%, but only when starch-containing glue was employed to attach the paper skin to the foam core. Waddar et al. [17] has done comparable study on the buckling and free vibration response of sandwich composites made of an epoxy-coated sisal fabric/core and a syntactic foam outside layer. Their research shows that cenosphere/epoxy syntactic foams, whether untreated or treated, may reduce weight in comparison to plain samples by 15.81% and 14.61%, respectively. These sandwich beams displayed global buckling modes devoid of wrinkles or skin delamination. Currently, a wide range of polymer mixtures, filler materials, micro-scale reinforcements, and nano-scale reinforcements are considered in the research of syntactic foam. This study examines how these materials are processed and how that affects the syntactic foam's physical characteristics, including deformation and fracture mechanics [18]. The impact strength and flexural modulus of hybrid syntactic foam, which was tested against traditional hollow glass microballoon syntactic foam, were astoundingly improved. Additionally, they looked at how the hollow glass microballoons' microstructure and wall thickness influenced the syntactic foam cores and discovered significant improvements in flexural strength and specific flexural strength of 71% and 68%, respectively [19]. Additionally, syntactic foam has significantly enhanced the mechanical performance of composite materials [20]. It raised the compressive strength of solid glass microspheres by 8.6% over cured epoxy and enhanced the damping properties of 6061Al/fly ash foam in comparison to the matrix alloy [21]. While their overall density has dropped, sandwich composites constructed of glass fiber-reinforced plastic have improved in terms of structural performance, energy absorption capacity, peak load, and stiffness. In ballistic testing, composite sandwich materials have shown themselves to be effective transporters of bending stress and impact resistance [22, 23]. For instance, Ahmadi et al. [2] studied the effects of high-velocity loading on sandwich panels with foam cores and woven fiberglass skins and came to the conclusion that the main reasons for foam core failure were skin crushing and delamination, which accounted for a significant amount (58–80%) of the total energy absorbed. Garay et al. [9] also investigated the effects of various core materials (PVC and PET) on the mechanical characteristics of sandwich panels with glass fiber coverings. In tests for flatwise tensile, flatwise compression, and flatwise shear, they discovered that the PVC core was superior; nevertheless, the use of the PET core was dependent upon the particular loading circumstances. The kind of face-sheet had a less impact than the thickness, according to Ashraf's investigation on how the thickness of the face-sheet influenced the compression properties of sandwich composites [11]. By changing the volume percent of fiberglass, Karthikeyan et al. [5] were able to increase the flexural modulus of syntactic foam cores. With respect to cell size and wall thickness, the characteristics of the core material were changed.

The tensile properties of hybrid sandwich composites made of Kevlar, Jute, and syntactic foam were not previously examined, according to the rich literature on hybrid sand witch composites. Determining the effects of skin material selection, material density, and percentage of reinforcement on the tensile properties of hybrid sandwich composites made of Kelvar, jute, and synthetic foam requires a structured approach that combines Taguchi experimental design and analysis of variance (ANOVA). This is what the current investigation aims to do.

2. Experimentation

2.1 Materials and fabrication

Synthetic foam core material (e.g., polyurethane foam) of specified density variations were used as main material for the present investigation. Kevlar fiber (Aramid fiber) of density 1.450 g/cm^3, Jute fiber (Natural fiber) of density 1.500 g/cm^3, syntactic foam (Synthetic fiber) of density 1.096 g/cm^3 and matrix resin of density 1.150 g/cm^3 were used for fabricating the hybrid composite. Appropriate adhesive was used bonding skin and core materials. The core preparation includes the following steps. The synthetic foam core material was cut into uniform dimensions. The skin materials (Kelvar, Jute, Synthetic) were fabricated to the necessary dimensions and configurations. The sandwich composites were fabricated by adhering skin materials to both surfaces of the core material using the epoxy adhesive LY556. Several composite samples were created using different combinations of skin materials, core densities, and reinforcement percentages, following the Taguchi L9 orthogonal array or design of experiments (DOE) method, as presented in Table 1. The sand witch composite photograph is presented in Figure 1, while the process of preparing the composite is illustrated in Figure 2. Figure 3 displays the standard diagram illustrating the sequence of sandwich composites composed of Kevlar, Jute, and Foam.

Table 1. Skin materials combinations

Sl.No.	Skin Material	Density gm/cm^3	Percentage of Reinforcement	Ultimate Tensile Strength (MPa)
1	Jute +Jute	40	25	44
2	Jute +Jute	60	50	51
3	Jute +Jute	80	75	52
4	Jute + Kevlar Fiber	40	50	50.5
5	Jute + Kevlar Fiber	60	75	54
6	Jute + Kevlar Fiber	80	25	55
7	Kevlar Fiber + Kevlar Fiber	40	75	56
8	Kevlar Fiber + Kevlar Fiber	60	25	52.5
9	Kevlar Fiber + Kevlar Fiber	80	50	61

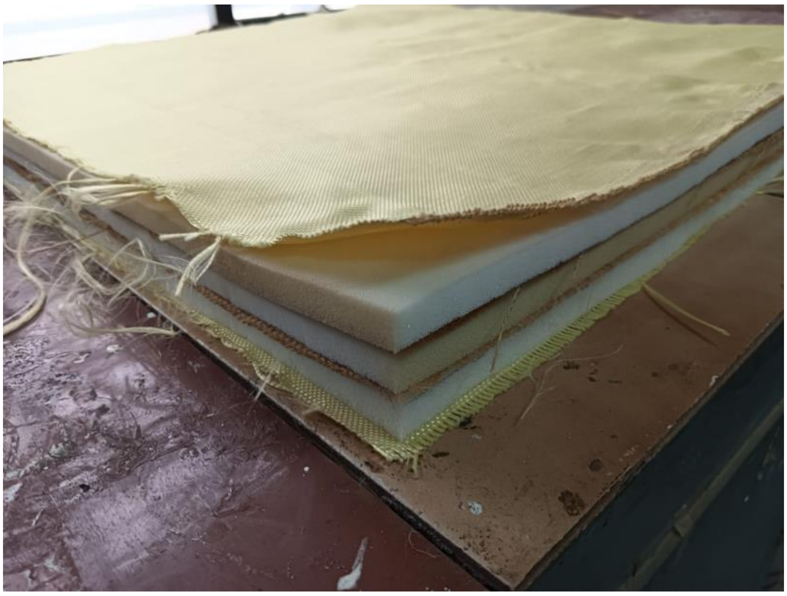


Figure 1. Photograph of sandwich composite.

Figure 2. Sandwich composite preparation.

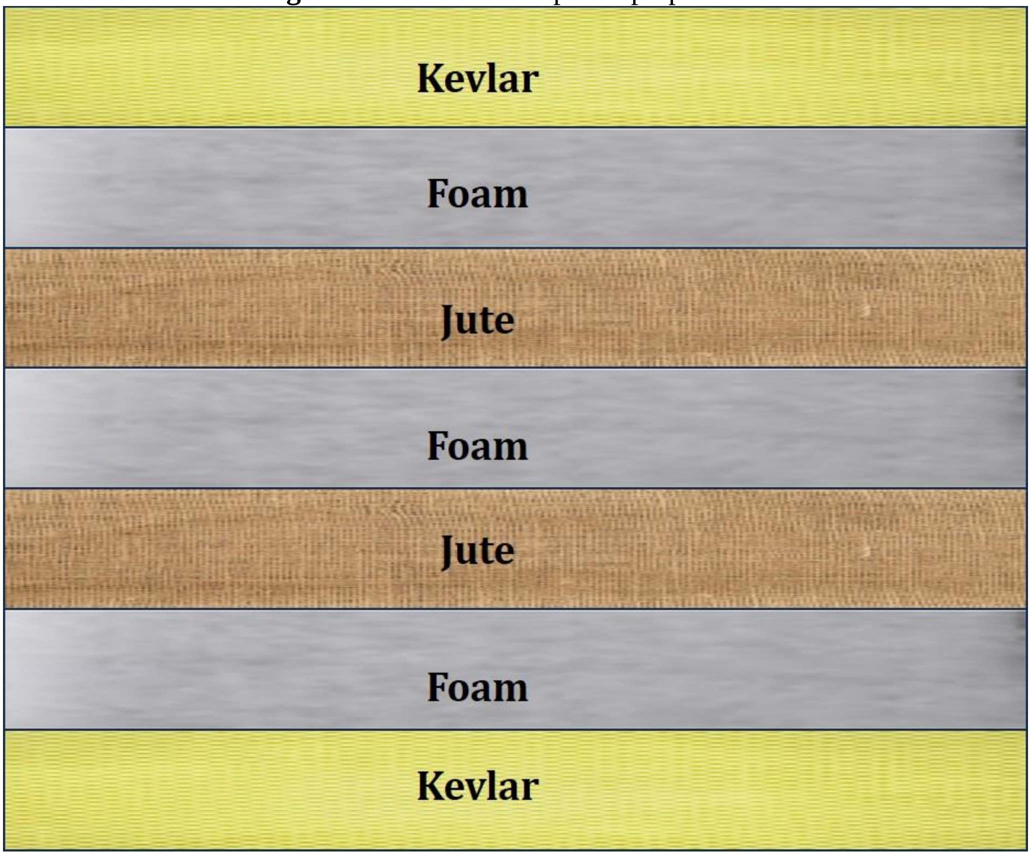


Figure 3. Typical diagram of the sequence of sandwich composites of Kevlar/Jute/Foam.

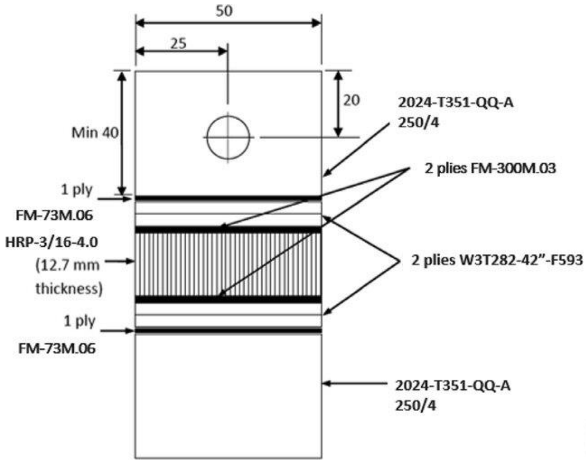
2.2 Tensile testing

The sandwich composite samples were subjected to tensile testing using a universal testing machine, following the guidelines specified in ASTM C297 testing specifications, as depicted in Figure 4a and b. The tension test samples were meticulously fabricated, precisely trimmed to dimensions of 120mm in length, 34mm in width, and with a thickness of 17mm.

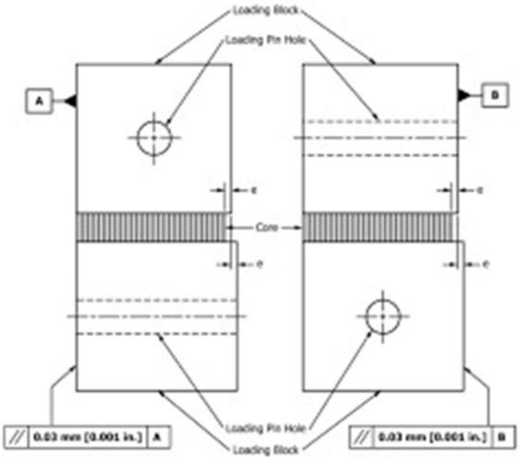
The testing procedure followed the guidelines set by ASTM C297 standards, which offer a comprehensive framework for conducting tensile tests on flat sandwich constructions. As per ASTM C297, the specimens were affixed to the testing machine using a suitable gripping system to guarantee a firm and consistent clamping. Adhering to this standardized mounting procedure is essential for obtaining precise and dependable measurements of tensile strength and modulus.

The specimens, which were prepared to meet the specified dimensions, were firmly positioned in the grips of the universal testing machine. This apparatus exerts a regulated and progressively augmenting force on the specimens until they break, while simultaneously measuring different mechanical characteristics at each stage.

Figure 4c visually depicts the tensile testing specimens, displaying photographs that illustrate the precise configuration and dimensions of the samples utilized in the study. These images provide a visual representation that aids in comprehending the physical arrangement of the specimens and their positioning within the testing machine.



(a)



(b)

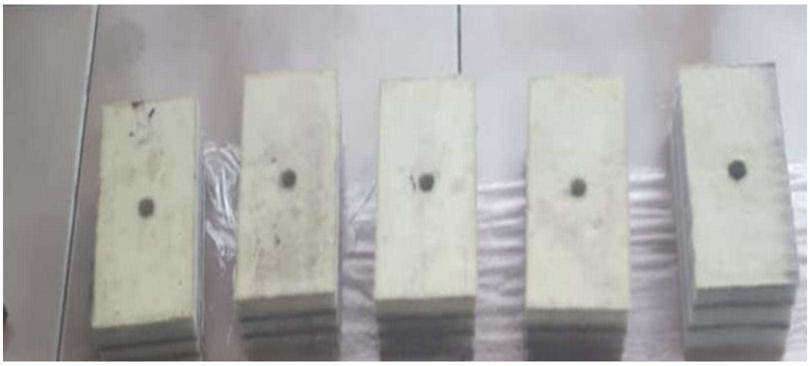


Figure 4. Photograph of Test specimens and standards.

2.3 Taguchi Experimental Design and Analysis of Variance (ANOVA)

The Taguchi experimental design was applied to systematically vary the levels of factors (skin material, core density, and reinforcement percentage). The experiments were designed and conduced according to the Taguchi L9 orthogonal array or as per the chosen design matrix. The randomization was ensured and replicate experiments to account for variability.

The experimental data was analyzed using ANOVA (Table :1) to determine the significance of each factor (skin material, core density, and reinforcement percentage) and their interactions on tensile properties. The main effects and interaction effects were calculated. The contributions of each factor to the observed variations in tensile properties were assessed. The test data, including tensile strength, modulus, and any other relevant observations were recorded, in a systematic manner. The Skin Material, which includes three categories (jute + jute, jute + Kelvar fiber, Kelvar + Kelvar fiber), exhibits an F-Statistic of 10.30 with a p-value of 0.088. This indicates a possible significant impact on the ultimate tensile strength. This suggests that the selection of skin material can have a significant impact on the dependent variable. Regarding Density, which is divided into three categories (40 g/cc, 60 g/cc, 80 g/cc), the F-Statistic of 6.29 and a p-value of 0.137 suggest that density might have a noticeable impact on ultimate tensile strength. The findings indicate that the density of the skin material may play a role in the observed variations in tensile strength. On the other hand, when examining the Percentage of Reinforcement, which is divided into three categories (25%, 50%, 75%), the statistical analysis reveals an F-Statistic of 3.13 and a p-value of 0.242. This suggests that the impact on ultimate tensile strength may be relatively minor when compared to the influence of skin material and density. The degree of reinforcement may not have a significant effect on the response variable. The Residual Error, with 2 degrees of freedom, represents the portion of variability in the model that cannot be explained. It quantifies the discrepancies between the actual and anticipated values. Based on the ANOVA results, it can be inferred that Skin Material and Density have a more significant impact on the variability in ultimate tensile strength compared to the Percentage of Reinforcement. This conclusion is drawn from considering the overall variability in the response variable, as represented by the Total with 8 degrees of freedom.

Table 1 : Analysis of Variance.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Skin Material	2	84.722	84.722	42.361	10.30	0.088
Density	2	51.722	51.722	25.861	6.29	0.137
Percentage of Reinforcement	2	25.722	25.722	12.861	3.13	0.242
Residual Error	2	8.222	8.222	4.111		
Total	8	170.389				

3. Results and discussion

3.1 Tensile properties

The effect of several skin material combinations on the ultimate tensile strength of foam hybrid composites was examined in the study. The tensile properties are shown Table 2. Three combinations—jute + jute, jute + Kelvar fiber, and Kelvar + Kelvar fiber—were taken into account.
Jute + Jute: The composite with jute skins on both sides showed a moderate ultimate tensile strength, which is consistent with the behavior predicted of natural fiber-reinforced composites.
Jute + Kelvar Fiber: Compared to the jute + jute combination, a pronounced improvement in ultimate tensile strength was seen when Kelvar fiber was added as one of the skin components. This is explained by the improved mechanical qualities of Kelvar fiber, which raise the composite's overall tensile strength.
Combining Kelvar skins with Kelvar fiber increased the ultimate tensile strength and demonstrated the material's considerable contribution. The Kelvar + Kelvar arrangement had the highest tensile strength of all the combinations, demonstrating the high-strength synthetic fibers' potential for reinforcing.
A significant factor impacting the general characteristics of sandwich composites is the density of the skin materials. We looked at skin materials with densities of 40 g/cc, 60 g/cc, and 80 g/cc. Composites with lower ultimate tensile strength were produced when skin materials with a lower density (40 g/cc) were used. The skins' reduced stiffness and thus lower tensile strength could have been caused by the lower density. The ultimate tensile strength of skin materials with a modest density of 60 g/cc was balanced. The weight and mechanical performance seem to be well-compromised in this density range. In comparison to their lower-density equivalents, composites using high-density skin materials (80 g/cc) showed greater ultimate tensile strength. The skins' better tensile qualities were probably the result of the higher density giving them more stiffness.

Table 2: Effect of skin material combinations on the ultimate tensile strength.

Sl.No.	Skin Material	Density (gm/cm^3)	Percentage of Reinforcement	Ultimate Tensile Strength (MPa)
1	Jute +Jute	40	25	44
2	Jute +Jute	60	50	51
3	Jute +Jute	80	75	52
4	Jute + Kevlar Fiber	40	50	50.5
5	Jute + Kevlar Fiber	60	75	54
6	Jute + Kevlar Fiber	80	25	55
7	Kevlar Fiber + Kevlar Fiber	40	75	56
8	Kevlar Fiber + Kevlar Fiber	60	25	52.5
9	Kevlar Fiber + Kevlar Fiber	80	50	61

The effects of various reinforcing percentages on the ultimate tensile strength of foam hybrid composites were examined. 25%, 50%, and 75% reinforcing percentages were taken into consideration. When compared to non-reinforced composites, composites with 25% reinforcement showed a little gain in ultimate tensile strength. This indicates that while a lower reinforcement percentage can still improve tensile characteristics, the impact is constrained. The ultimate tensile strength significantly increased at the 50% reinforcing level. This suggests that mechanical performance is significantly improved with a moderate reinforcement percentage. The composites with the highest ultimate tensile strength had a reinforcing content 50%. Beyond the level of 50% reinforcement, however, the pace of strength gain appeared to slow down. This implies that larger reinforcement percentages may result in declining returns. The findings of this study highlight how crucial it is to choose the right skin material combinations, densities, and reinforcing percentages to customize the ultimate tensile strength of foam hybrid composites to particular application requirements.

3.2 Taguchi analysis

The impact of various combinations of skin materials, densities, and reinforcement proportions on the maximum tensile strength of foam hybrid composites was assessed through Taguchi analysis. Figure 5 displays major effect plots that visually demonstrate the influence of each component on the average ultimate tensile strength.

Regarding the combinations of skin materials (jute + jute, jute + Kelvar fiber, Kelvar + Kelvar fiber), the primary effect plot indicates that the Kelvar + Kelvar fiber combination produces the highest average ultimate tensile strength. This is followed by jute + Kelvar fiber, while jute + jute shows the lowest strength. This highlights the substantial influence of skin material combinations, with a preference for Kelvar-based combinations over jute-based ones.

The analysis of the correlation between mean ultimate tensile strength and skin material densities (40 g/cc, 60 g/cc, 80 g/cc) reveals a significant positive relationship. Specifically, higher densities are associated with higher mean tensile strength. Composites featuring skin materials with a density of 80 g/cc demonstrate the greatest strength, underscoring the significance of choosing skin materials with higher densities to improve tensile strength.

The main effect plot demonstrates a consistent rise in the average ultimate tensile strength as the reinforcement percentage increases, with different percentages of reinforcement (25%, 50%, 75%) being considered. The maximum strength is observed at a reinforcing percentage of 50%, with the density of the foam being 80 gm/cc, thus emphasizing the direct relationship between the density and the tensile strength.

The robustness of the process, evaluated using the Signal-to-Noise (SN) ratio, is illustrated in Figure 6. The SN ratio major effect plot demonstrates that combinations utilizing Kelvar outperform those utilizing jute, with the Kelvar + Kelvar fiber combination exhibiting the highest SN ratio. Conversely, the utilization of both jute and jute results in the most unfavorable signal-to-noise ratio (SN ratio), suggesting a high vulnerability to variations in the manufacturing process.

When analyzing the SN ratios associated with different skin material densities, the main effect plot confirms that skin materials with higher densities are more important. Specifically, the SN ratio is highest for skin materials with a density of 80 g/cc. The main effect plot for SN ratios reveals that increasing the percentage of reinforcement has a positive impact on the stability of tensile strength.

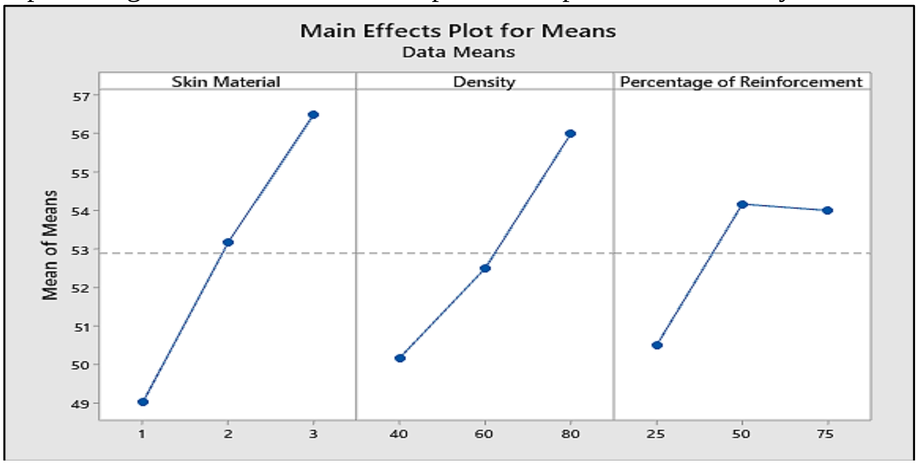


Figure 5. Main effect plots for Means.

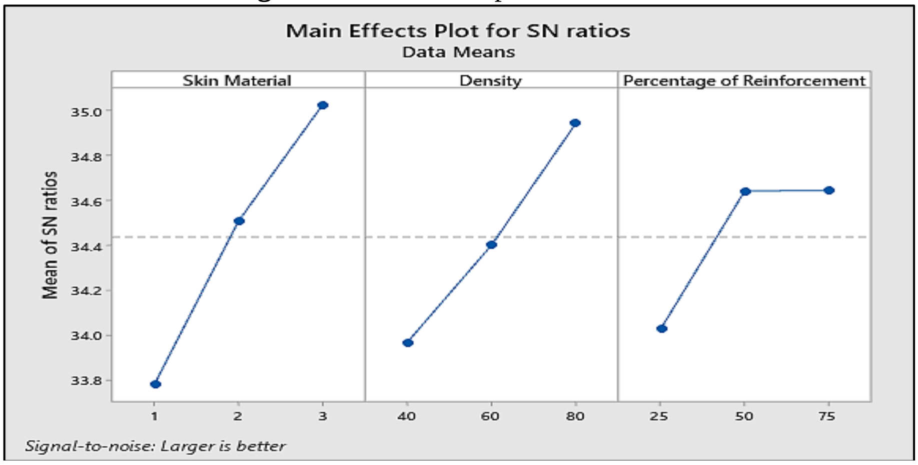


Figure 6. Main effect plots for SN ratios.

4. Conclusions

Following a structured approach that combines Taguchi experimental design and analysis of variance (ANOVA), the following conclusions regarding the influence of skin material selection, material density, and percentage of reinforcement on the tensile properties of Kelvar/jute/synthetic foam hybrid sandwich composites were reached in the current investigation.

- Combinations made of Kelvar have better tensile qualities than those made of jute, emphasizing the value of using high-strength synthetic fibers. Additionally, skin material density was also important, with intermediate densities frequently producing the best tensile strength.
- The study concludes that the skin material combinations selected have a significant influence on the ultimate tensile strength of foam hybrid composites. Kelvar-based combinations, such as Kelvar + Kelvar fiber, consistently outperform jute-based combinations, with the former demonstrating the highest tensile strength.
- Skin materials with a higher density, particularly those with a density of 80 g/cc, produce composites with higher ultimate tensile strength. This implies that the stiffness provided by higher-density skin materials significantly contributes to the overall mechanical performance of the foam hybrid composites.
- The research shows that the percentage of reinforcement has a significant impact on the ultimate tensile strength of foam hybrid composites. While 25% reinforcement results in a modest improvement, 50% reinforcement results in a significant improvement. Beyond 50%, however, the rate of strength gain slows, implying diminishing returns.
- The mean ultimate tensile strength major effect plots show that combinations based on Kelvar consistently outperform those based on jute. The Kelvar + Kelvar fiber combination has the highest Signal-to-Noise (SN) ratio, indicating better performance and resistance to process fluctuations.
- To achieve the desired mechanical properties, the study identifies the need to balance skin material combinations, densities, and reinforcement percentages. Furthermore, it implies that there is a point of diminishing returns after a certain level of reinforcement.

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Conflict of interest:

Authors here by declared that, there is no conflict of interest.

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