



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

Sheemaraya^{1*}, H C Chittappa², R. Suresh Kumar³, Krishnan Bandyopadhyay⁴,
Nanditha h.g⁵, Madhusudhana H K⁶

^{1,2}Department of Mechanical Engineering, University Visvesvaraya College of Engineering, Bengaluru – 560001, Karnataka, India.

³Department of Mechanical Engineering, B. M. S. College of Engineering, Bengaluru- 560019, Karnataka, India.

^{4,5} Department of Medical electronics Engineering, Dayananda Sagar College of Engineering, Bangalore - 560078, Karnataka, India.

⁶School of Mechanical Engineering, K L E Technological University, Hubballi- 580021, Karnataka, India.

*Corresponding author's E-mail: bheema.rk@gmail.com

Article History	Abstract
Received: 06 June 2023 Revised: 05 Sept 2023 Accepted: 30 Oct 2023	<p><i>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.</i></p>
CC License CC-BY-NC-SA 4.0	<p>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)</p>

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 sandwich composites. Determining the effects of skin material selection, material density, and percentage of reinforcement on the tensile properties of hybrid sandwich composites made of Kevlar, 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. Materials And Methods

Experimentation

Fabrication

Synthetic foam core material (e.g., polyurethane foam) of specified density variations were used a main material for the present investigation. Kevlar fiber (Aramid fiber-reinforced composite) of 1.450 (g/cm³), jute fiber (Natural fiber-reinforced composite) of 1.500 (g/cm³), syntactic foam (Synthetic fiber-reinforced composite) of 1.096 (g/cm³) and matrix resin of 1.150 (g/cm³) were used as skin materials. Fibers or fillers for reinforcing the composite (e.g., glass fibers, carbon fibers, etc.) with varying percentages were used reinforcing agents. Appropriate adhesive were 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 (Kevlar, Jute, Synthetic) was fabricated into required dimensions and configurations. The sandwich composites were assembled by bonding skin materials to both sides of the core material using the designated adhesive. Multiple composite samples were prepared with varying combinations of skin materials, core densities, and reinforcement percentages as per the Taguchi L9 orthogonal array or design of experiments (DOE), as shown in Table 1. The photograph of the sandwich composite is displayed in Figure 1 and the composite preparation is shown in Figure 2. The typical diagram of the sequence of sandwich composites of Kevlar/Jute/Foam is shown in Figure 3.

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 impregnated and cured sandwich composite



Figure 2. Sandwich composite preparation

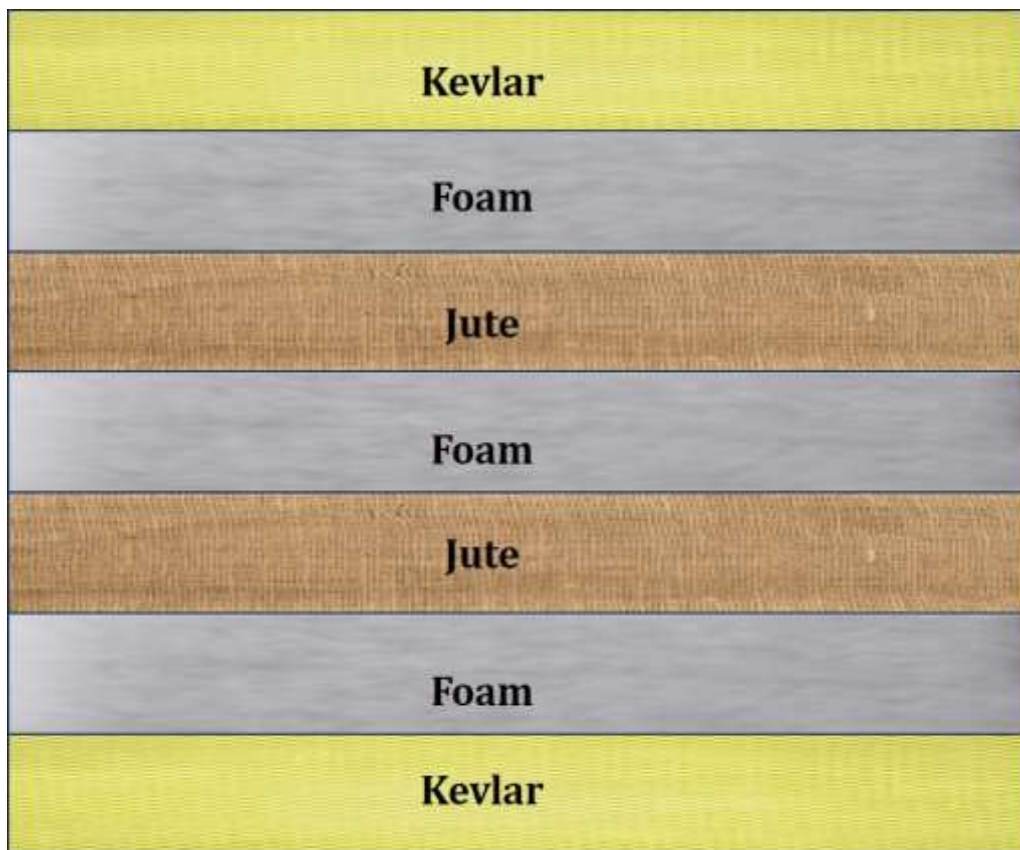
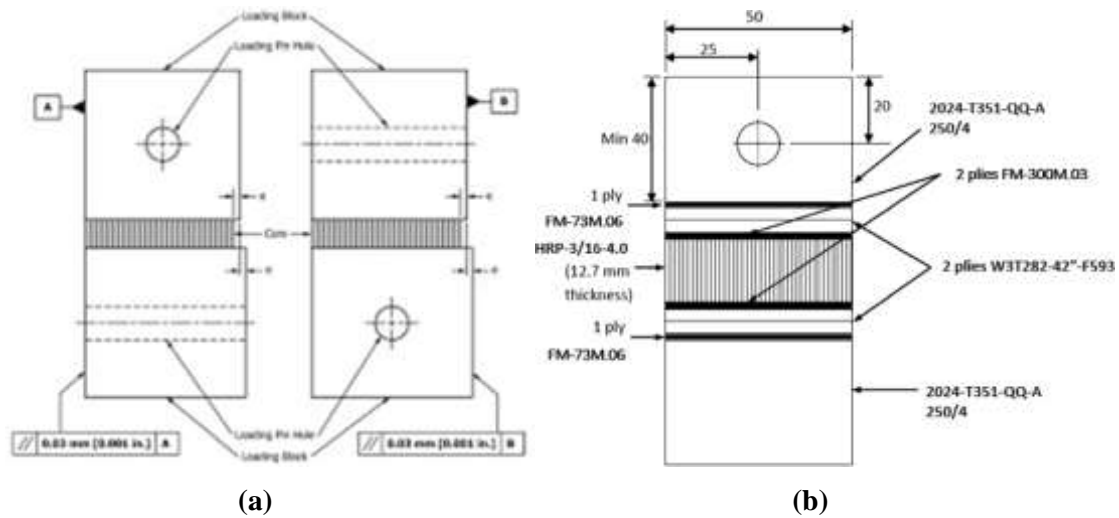


Figure 3. Typical diagram of the sequence of sandwich composites of Kevlar/Jute/Foam

Tensile testing

The tensile testing was performed on the prepared sandwich composite samples using a universal testing machine. The ASTM C297 or equivalent standards for tensile testing specifications shown in figure 4(a & b). The tension test samples were cut into a size of 120mm length, 34mm width and 17mm thick. The tensile strength, modulus, and other relevant mechanical properties were recorded. The photographs of the tensile specimens are shown in Figure 4 c.



(c)

Figure 4. Photograph of Test specimens and standards

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 conducted 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 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 ANOVA results were interpreted to identify the significant factors and interactions affecting tensile properties. The optimal combination of skin material, core density, and reinforcement percentage that leads to the desired tensile properties were determined. Finally, the findings were summarized regarding the effects of skin material, core density, and reinforcement percentage on the tensile properties of Kelvar/Jute/Synthetic Foam hybrid sandwich composites.

3. Results and Discussion

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 1. 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.

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 of 75%. 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.

Taguchi analysis

The effect of skin material combinations, skin material densities, and the proportion of reinforcement on the ultimate tensile strength of foam hybrid composites were assessed using Taguchi analysis. The major effect plots for mean values show how each component affects the mean ultimate tensile strength in a graphical manner (as shown in Figure 5). Following is the major effect plot for the mean ultimate tensile strength in relation to the skin material combinations (jute + jute, jute + Kelvar fiber, and Kelvar + Kelvar fiber): The Kelvar + Kelvar fiber combination produces the highest mean ultimate tensile strength, followed by the jute + Kelvar fiber combination, according to the main effect plot. The combination of jute and jute exhibits the lowest mean tensile strength. This suggests that the type of skin material combination has a major impact on tensile strength, with Kelvar-based combinations outperforming jute-based ones by a wide margin.

The following main effect plot shows the relationship between mean ultimate tensile strength and the densities of the skin material (40 g/cc, 60 g/cc, and 80 g/cc): The major effect graphic shows that as skin material density rises, the mean ultimate tensile strength typically climbs as well. The highest mean tensile strength is seen in composites with skin material densities of 80 g/cc, while the lowest is seen in composites with a density of 40 g/cc. This emphasizes how crucial it is to choose higher-density skin materials in order to improve tensile strength.

The following main effect plot for mean ultimate tensile strength considering various reinforcing percentages (25%, 50%, and 75%): The mean ultimate tensile strength constantly rises with an increasing percentage of reinforcement, as seen by the main effect plot. The mean tensile strength of composites with 75% reinforcement is the highest, while that of composites with 25% reinforcement is the lowest. The correlation between reinforcing percentage and tensile strength is highlighted by this.

The resilience of the process is evaluated using the Signal-to-Noise (SN) ratio, which indicates the quality characteristic to noise ratio (as shown in Figure 6). Higher SN ratios in this situation denote better performance. The following primary effect graphic depicts the SN ratios connected to various combinations of skin materials: The major effect plot for SN ratios supports the conclusion that combinations based on Kelvar outperform those based on jute. The combination of Kelvar + Kelvar fiber yields the highest SN ratio, demonstrating its reliability in attaining higher tensile strength. The combination of jute and jute, on the other hand, has the lowest SN ratio, indicating its susceptibility to process fluctuations. The following is the primary effect plot for SN ratios related to various skin material densities: The significance of higher-density skin materials for producing robust tensile strength is reiterated by the main effect plot for SN ratios considering skin material densities. The

highest SN ratio, which indicates a composite's resistance to process changes, is seen in materials with a skin material density of 80 g/cc. The major effect plot for SN ratios considering various reinforcement percentages is shown below: The favorable effect of increasing reinforcing percentage on the stability of tensile strength is highlighted by the main effect plot for SN ratios. Composites with 75% reinforcement have the highest SN ratios, which shows how resistant they are to process fluctuations.

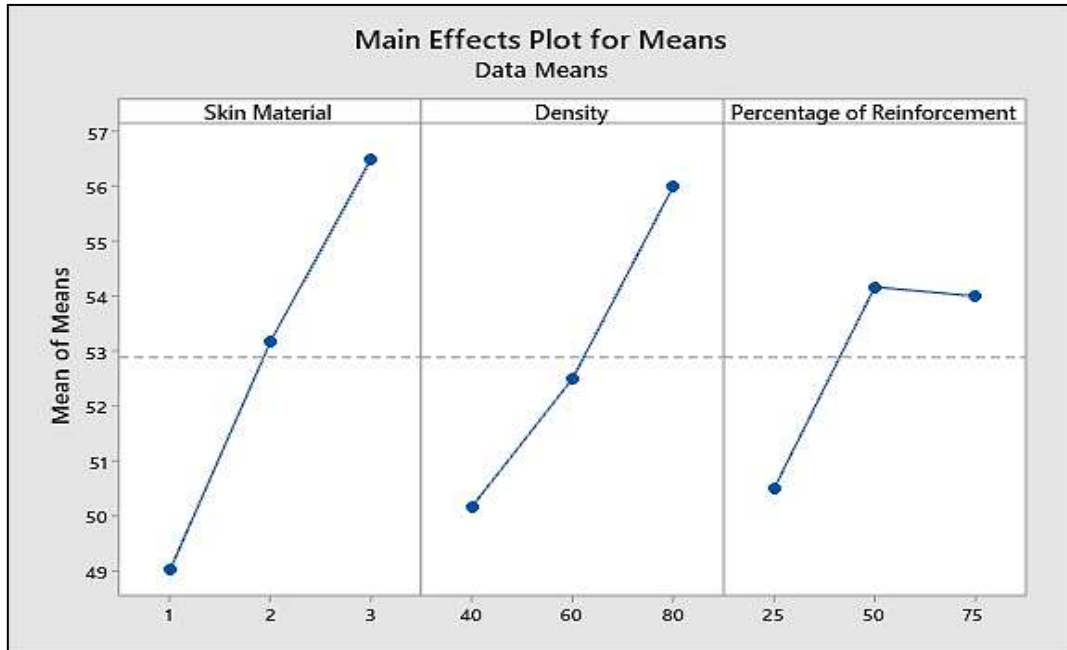


Figure 5. Main effect plots for Means

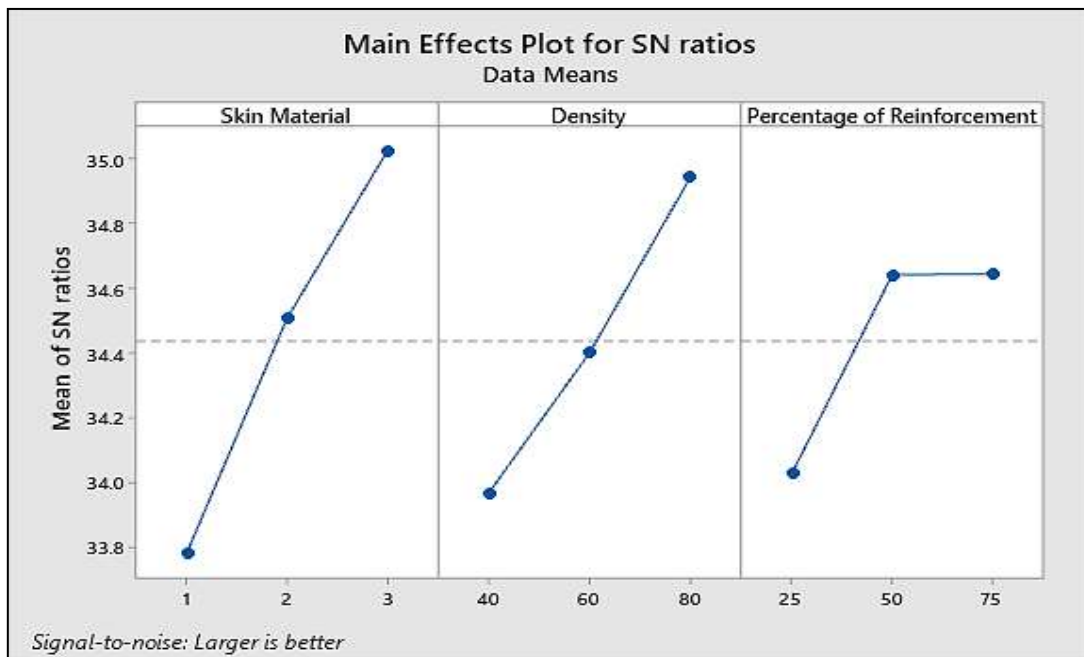


Figure 6. Main effect plots for SN ratios

4. Conclusion

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.

- Additionally, the degree of reinforcement had a substantial impact on the tensile qualities, with 50% of reinforcement achieving a compromise between cost-effectiveness and improvement.
- With the help of these discoveries, engineers and designers who deal with foam hybrid composites may make wise judgments about the material to use and the design of the composite to get the desired tensile performance in different applications. To fully evaluate the feasibility of these composites in certain circumstances, more investigation could look into additional mechanical qualities and environmental factors.
- The Taguchi analysis offers important insights into the variables affecting the ultimate tensile strength of foam hybrid composites, showing main effect charts for mean and SN ratios. Superior tensile strength and robustness are consistently achieved by using Kelvar-based skin material combinations, larger skin material densities, and enhanced reinforcing percentages.
- For materials engineers and designers looking to maximize the mechanical performance and dependability of foam hybrid composites, these findings provide essential direction. They emphasize how important it is to choose the right materials and assembly techniques to obtain the requisite tensile qualities while ensuring the process' robustness against changes.
- In order to fully evaluate the suitability of these composites for particular applications, future study can explore the interactions between these elements and delve into other mechanical properties.

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