Investigation On Tensile Properties Of Aluminum 7075 - Silica Particles -Boron Fiber- Reinforced Hybrid Metal Matrix Composites

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Abstract: Hybrid metal matrix composites (MMCs), particularly those using an Aluminum 7075 (Al7075) base combined with silica particles and boron fibers, have emerged as a focal point in engineering for their superior strength-to-weight ratio. This study examines a composite of Al7075 reinforced with varying amounts of silica particles (0%, 2%, 4%, 6%) and boron fibers (1%, 3%, 5%, 7%). The research aims to discern the impact of these reinforcements on the composite's tensile properties. Employing the stir casting technique, these reinforcements were melted into the Al7075 matrix. The composites underwent tensile testing to gauge their mechanical performance, with a tensometer measuring tensile strength. The findings indicate that the inclusion of silica and boron fibers enhances tensile strength, with the greatest increase of 43.5% rise in tensile stress observed in the sample with 6% silica and 7% boron fiber. Variance analysis reveals that silica contributes 85.51% to the strength, boron fiber contributes 12.70%, and there is an error margin of 1.49%. Furthermore, a comparison of experimental, regression, and Artificial Neural Network (ANN) predicted values confirms consistency within an error margin of 5.86%.
Keywords: Metal matrix composites, Aluminium 7075, boron fibers, silica particles, stir casting, tensile properties, hybrid composites.

1. Introduction

Metal matrix composites (MMCs) have garnered significant attention in recent years as advanced materials with exceptional mechanical properties and lightweight characteristics. These composites consist of a metallic matrix reinforced with various materials such as fibers, particles, or whiskers, which significantly enhance their performance compared to traditional monolithic metals. MMCs find extensive applications in industries where high strength-to-weight ratios and improved mechanical properties are essential, such as aerospace, automotive, and defense.

Aluminium matrix composites are particularly appealing due to the inherent advantages of aluminium, including its low density, good corrosion resistance, and high thermal conductivity. Among the various aluminum alloys, Aluminum 7075 (Al7075) is widely used in aerospace and structural applications due to its high strength and excellent fatigue resistance. However, the inherent limitations of Al7075, such as low ductility and fracture toughness, necessitate the development of composite materials that can overcome these shortcomings.

In this context, the present research focuses on the fabrication and characterization of a novel hybrid MMC utilizing the stir casting process. The hybrid composite incorporates Al7075 as the matrix material and reinforces it with boron fibers and silica particles. Boron fibers are known for their high tensile strength, exceptional stiffness, and excellent thermal stability. Silica particles, on the other hand, possess desirable mechanical properties and can improve the wear resistance and thermal stability of composites.

The addition of boron fibers and silica particles aims to enhance the tensile properties of the Al7075 matrix, including ultimate tensile strength, yield strength, and elongation at failure. The stir casting process is chosen as the fabrication method due to its ability to produce composites with uniform distribution of reinforcements within the matrix. Through systematic variation of the weight percentages of boron fibers and silica particles, the effect of reinforcement content on the mechanical behaviour of the hybrid MMC will be investigated.

The investigation of the tensile properties of the Al7075-Boron Fiber-Silica Particles Reinforced Hybrid Metal Matrix Composites is crucial for understanding the potential of these materials in high-performance applications. By evaluating the performance of the composites, valuable insights can be gained into their suitability for lightweight structural components that require enhanced strength and ductility. Furthermore, this research contributes to the broader field of MMCs by providing a comprehensive understanding of the stir-casting process and the influence of different reinforcement types and contents on mechanical properties.

Overall, this study aims to contribute to the development of advanced composite materials with improved mechanical characteristics, paving the way for their application in industries where lightweight, high-strength materials are in demand.

2. Literature Review

Balasubramani Subramaniam et al., [1] The study reveals that the tensile results demonstrate significant improvement in the mechanical properties with the addition of boron carbide and coconut shell fly ash reinforcements. The composite materials exhibit enhanced tensile strength, increased yield strength, improved ductility, and better resistance to deformation. The findings highlight the potential of these hybrid composites for applications requiring a high strength-to-weight ratio and improved mechanical performance. Mohammed Imran et al., [2] The study reveals that the tensile results exhibit a notable improvement in the mechanical properties with the incorporation of graphite and bagasse ash reinforcements. The composites demonstrate increased tensile strength, enhanced yield strength, improved ductility, and better resistance to deformation. The findings suggest that the addition of these reinforcements positively influences the overall mechanical performance of the Aluminium-7075 composite material. This study highlights the potential of such hybrid composites for applications that require improved strength and mechanical properties. Muhammed Muddassir et al., [3] The tensile results demonstrate a significant enhancement in the mechanical properties of the composite material with the addition of silicon carbide particles. The composite exhibits increased tensile strength, improved yield strength, enhanced ductility, and better resistance to deformation. The findings suggest that the incorporation of silicon carbide particles positively influences the tensile behavior and mechanical performance of the Al-7075 matrix. This study highlights the potential of silicon carbide-reinforced composites for applications requiring improved strength and mechanical properties. Kapil Singh a et al., [4] Suggest that the tensile results reveal improved mechanical properties in the Al 7050 and Al 7075-based metal matrix composites. The composites exhibit enhanced tensile strength, increased yield strength, improved ductility, and better resistance to deformation compared to pure alloys. The findings indicate the potential of these composites for applications requiring high-strength materials. This review provides valuable insights into the mechanical behaviour of Al 7050 and Al 7075 composites, contributing to the understanding and development of advanced metal matrix composites. R. Karthigeyan et al., [5] Indicate that the tensile results demonstrate improved mechanical properties in the composite material. The composite exhibits enhanced tensile strength, increased yield strength, improved ductility, and better resistance to deformation compared to the unreinforced Aluminium 7075 alloy. The findings suggest that the incorporation of short basalt fibers positively influences the tensile behaviour and mechanical performance of the composite. This study highlights the potential of short basalt fiber-reinforced composites for applications requiring enhanced strength and mechanical properties. Sunil J Mangshetty et al., [6] reveals that the tensile results demonstrate significant improvements in the mechanical properties of the composite material. The composite exhibits enhanced tensile strength, increased yield strength, improved ductility, and better resistance to deformation compared to the pure Aluminium Alloy 7075. The findings suggest that the addition of SiC and fly ash reinforcements positively influences the tensile behaviour and mechanical performance of the composite. This study highlights the potential of SiC and fly ash-reinforced composites for applications requiring improved strength and mechanical properties. Mathivanan. S et al., [7] The study provides an overview of the tensile results reported in various studies. The reviewed literature suggests that Al 7075 metal matrix composites exhibit improved tensile strength, increased yield strength, enhanced ductility, and better resistance to deformation compared to the pure Al 7075 alloy. The findings emphasize the potential of Al 7075 metal matrix composites for applications requiring high-strength materials. This review paper provides valuable insights into the mechanical behavior of Al 7075 composites, contributing to the understanding and development of advanced metal matrix composites.

The literature reviews conducted on various metal matrix composites (MMCs) involving Aluminium 7075 (Al 7075) have consistently demonstrated the potential for significant improvements in mechanical properties. The incorporation of different reinforcements such as boron fiber, silica particles, graphite, bagasse ash, silicon carbide particles, short basalt fiber, and fly ash has shown positive effects on tensile strength, yield strength, ductility, and deformation resistance of the composites.

These findings highlight the ability of the reinforcements to enhance the overall mechanical performance of Al 7075 matrix composites. The reviewed studies consistently indicate that the addition of these reinforcements leads to improved tensile strength, increased yield strength, enhanced ductility, and better resistance to deformation when compared to the unreinforced Al 7075 alloy. This suggests that the reinforcements effectively contribute to the reinforcement of the matrix, resulting in composites with desirable mechanical properties.

Overall, the literature reviews consistently demonstrate that the incorporation of various reinforcements in Al 7075 matrix composites offers a viable approach to enhance the tensile properties and mechanical performance of the materials. Further research and development in this field can lead to the realization of advanced MMCs with improved strength, durability, and lightweight characteristics, opening up new opportunities for their utilization in diverse engineering applications.

3. Materials

3.1 Aluminium 7075

Aluminium 7075 (Al7075) is a widely used aluminium alloy in various industries, including aerospace, automotive, and structural applications. It is chosen as the matrix material in our research or study due to its exceptional mechanical properties and desirable characteristics.

Al7075 possesses high strength, making it suitable for applications requiring materials with excellent load-bearing capabilities. It has a high tensile strength, which refers to its ability to withstand tension without fracturing, making it ideal for components subjected to high-stress conditions. Additionally, Al7075 exhibits good fatigue resistance, allowing it to withstand cyclic loading without significant degradation in its mechanical properties. Important property of Al7075 is its low density, which contributes to its lightweight nature. This characteristic is highly desirable in industries where weight reduction is crucial for improving fuel efficiency and overall performance. Despite its low density, Al7075 maintains its strength and structural integrity, making it an attractive choice for lightweight structural components.

Al7075 demonstrates good corrosion resistance, particularly when compared to other aluminium alloys. This property is vital for applications where exposure to harsh environments, moisture, or corrosive substances is expected.

Overall, the selection of Al7075 as the matrix material in our research or study is justified by its exceptional mechanical properties, including high tensile strength, good fatigue resistance, low density, and corrosion resistance. These properties make it a suitable material for the development of high-performance metal matrix composites that can meet the demanding requirements of various industries. Table 3.1 shows the chemical combination on Al7075 and Table 3.2 shows the properties of Boron fiber. And Table 3.3 shows the material composition in percentage.

3.2 Boron fiber

The use of boron fiber as a reinforcement material in our research or study on Aluminum 7075 matrix composites offers several advantages. Boron fiber exhibits remarkable mechanical properties, including high tensile strength, stiffness, and low density. Its high tensile strength contributes to the overall strength and load-bearing capabilities of the composite material. Additionally, boron fiber provides excellent stiffness, enhancing the structural integrity and rigidity of the composite. Its low density ensures that the composite remains lightweight without compromising on strength or performance. Furthermore, boron fiber demonstrates excellent thermal stability and chemical inertness, making it suitable for applications that involve high temperatures or exposure to corrosive environments. Overall, the incorporation of boron fiber as a reinforcement in the Aluminum 7075 matrix enhances the mechanical properties and expands the potential applications of the composite material.

3.3 Silica particles

The inclusion of silica particles as a reinforcement material in our research or study on Aluminium 7075 matrix composites brings several benefits. Silica particles possess unique properties that enhance the mechanical characteristics of the composite material.

Firstly, silica particles offer improved tensile properties to the composite. They contribute to increased tensile strength, enhancing the material's ability to withstand stretching forces without failure. This improved strength is crucial for applications requiring high load-bearing capabilities.

Secondly, the addition of silica particles improves the stiffness and rigidity of the composite. The particles reinforce the matrix material, increasing its resistance to deformation under applied loads. This enhanced stiffness enhances the overall structural integrity of the composite, making it suitable for applications that require dimensional stability and resistance to bending or flexing.

Silica particles contribute to the density reduction of the composite material. Silica has a lower density compared to aluminium, enabling the creation of lightweight composites. This is particularly advantageous for industries where weight reduction is essential, such as aerospace or automotive applications, as it leads to improved fuel efficiency and performance. These advantages make silica particle-reinforced composites suitable for a wide range of applications requiring lightweight, strong, and durable materials.

Table 3.1: Chemical composition of Al7075

ELEMENT	CHEMICAL COMPOSITION
Zinc	5.1-6.1
Magnesium	2.1-2.9
Copper	1.2-2
Iron	0.5
Silicon	0.4
Manganese	0.3
Chromium	0.18-0.28
Titanium	0.20
Aluminium	Balance

Table 3.2: Properties of boron fiber

PARTICULAR	PROPERTY
Particle size	30-100 µm
Density	2.61 gm/cm3
Thermal Expansion	2.5 × 10−6 /˚C

Table 3.3: Material composition in percentage

Sl no	Al7075(%)	Silica(%)	Boron fibre(%)
1	99	0%	1
2	97		3
3	95		5
4	93		7
5	97	2	1
6	95		3
7	93		5
8	91		7
9	95	4	1
10	93		3
11	91		5

12	89		7
13	93	6	1
14	91		3
15	89		5
16	87		7

4. Composite Preparation

Using a 6-kW electrical resistance furnace, stir casting was used to create hybrid Al7075-Boron Fibre-Silica composites. A picture of the casting furnace utilized in this investigation may be seen in Figure 4.1. The melting furnace's specs are displayed in Table 4.1 and four different types of composites were created as given in Table 3.3.

These compositions were melted in the furnace at a temperature of 750 °C. For fifteen minutes, a mechanical stirrer spinning at 200–300 rpm was used to stir the molten alloy. The composite materials were kept at a temperature of 750 °C until they melted, at which point they were put into metallic moulds.

Fig 4.1: Picture of a furnace for melting aluminium

Table 4.1: Specifications of aluminum melting furnace

Particulate	Description
Temperature	12 000 °C
Melting capacity	5 kg
Heating element	Silicon carbide (6Nos)
Controller	Thyristerized PID Temperature – 6 Kw with power pack
Crucible	Graphite
Power	230 volts 6 kw
Stirrer	50–1000 rpm Remi made

5. Tensile Strength Test

The tensile strength test is a crucial aspect of evaluating the mechanical properties of the Aluminum 7075 matrix composites reinforced with different materials. The tensile strength test is conducted to measure the maximum stress that the composite material can withstand under tensile loading.

During the test, standardized specimens are prepared according to specific dimensions and shape. These specimens are subjected to an axial load in a controlled testing environment using tensometer. The machine gradually applies tensile force to the specimen until it reaches failure or fracture.

The applied force and corresponding deformation are recorded throughout the test, allowing us to calculate various mechanical properties, including tensile strength. Tensile strength is determined by dividing the maximum load at failure by the original cross-sectional area of the specimen.

The results obtained from the tensile strength test provide valuable insights into the performance and structural integrity of the Aluminum 7075 matrix composites. They help assess the effectiveness of different reinforcement materials in improving the tensile strength of the composites. The data obtained from the test also contribute to validating the suitability of the composites for specific applications that require high strength and resistance to tensile forces. Overall, the tensile strength test plays a vital role in our research or study by quantifying the tensile properties and evaluating the effectiveness of reinforcement materials in enhancing the overall strength and performance of the Aluminum 7075 matrix composites**.** Figure 5.1 shows tensile test specimens.

Fig 5.1: Tensile test specimen

6.1 Tensile strength results

The tensile test results for different weight % combinations of matrix and reinforcing material are studied and to predict results following graphs are been plotted for (0,2,4,6 wt. %) of Silica varying with (1,3,5,7 wt. %) Boron fibre Figure 3(a), Figure 3(b), Figure3(c) and Figure 3(d) shows the trend for the results obtained for tensile test.

Observations from Figure 3 suggest a clear trend: an increase in the weight percentage of silica from 0% to 6% corresponds with a rise in the tensile stress of the composite. Similarly, elevating the boron fiber content from 1% to 7% results in enhanced tensile strength of the material. These patterns imply that incorporating silica and boron fiber enhances the material's capacity to resist forces that elongate or stretch it.

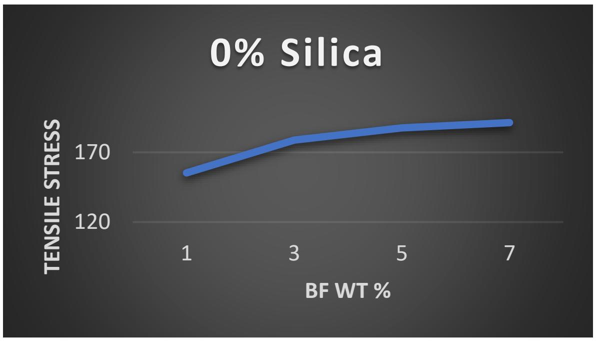

Fig 3(a): for 0% Silica

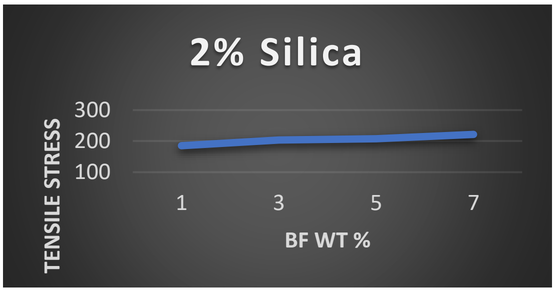

Fig 3(b): for 2% Silica

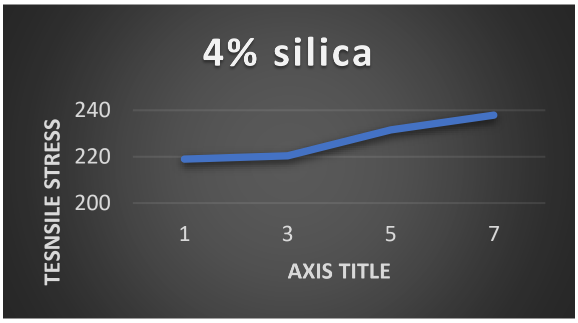

Fig 3(c): for 4% Silica

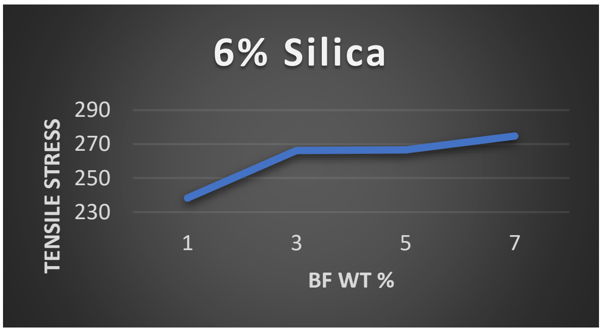

Fig 3(d): for 6% Silica

Fig 3: Results of Tensile Strength

The increments in tensile strength with varying weight percentages of boron fiber display distinct rates of change, as depicted in Figure 3. Specifically, for the composite with 0% silica, the increase in tensile stress is as follows: a 13% rise when boron fiber content goes from 1% to 3%, a 4.7% gain from 3% to 5% boron fiber, and a 2% increase from 5% to 7% boron fiber, according to Figure 3(a). For the composite with 2% silica, Figure 3(b) shows a 9% increase in tensile stress from 1% to 3% boron fiber, a 2% rise from 3% to 5% boron fiber, and a 6.2% increase from 5% to 7% boron fiber. In the case of 4% silica, Figure 3(c) illustrates a minimal 0.6% increase in tensile stress from 1% to 3% boron fiber, a 4.8% jump from 3% to 5% boron fiber, and a 2.6% increase from 5% to 7% boron fiber. Lastly, for the composite with 6% silica, Figure 3(d) reveals a 10.5% increase in tensile stress from 1% to 3% boron fiber, a negligible 0.1% increment from 3% to 5% boron fiber, and a 3% rise from 5% to 7% boron fiber.

6.2 Results of Taguchi model, ANOVA and ANN

6.2.1 Taguchi model

Employing the L16 array and a two-factor, four-level Taguchi model through Minitab software facilitates the identification of the optimal factor levels. The R-square value, or the coefficient of determination derived from the Taguchi method, is presented in Figure 6.1 as 97.87%. This high percentage signifies a strong correlation between the experimental results for tensile stress and the model's predictions, indicating a well-fitted model as per the Signal-to-Noise (SN) ratio model summary provided by the Taguchi method

Model Summary

S	R-Sq	R-Sq(adj)
0.2602	97.87%	96.45%

Fig 6.1: Model coefficients summary of SN ratio

Figure 6.2 illustrates the impact of varying percentages of silica and boron fiber on the Signal-to-Noise (SN) ratio concerning tensile stress, where a higher tensile stress value is preferable. The figure clearly demonstrates that as the percentages of silica and boron fiber increase, there is a corresponding rise in the SN ratio, implying an enhancement in tensile stress. Meanwhile, Figure 6.3 presents the residual plot for the SN ratio, suggesting that the data is normally distributed.

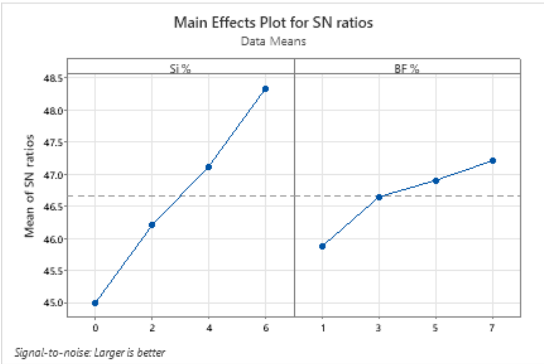

Fig 6.2: Effect plot for SN ratio

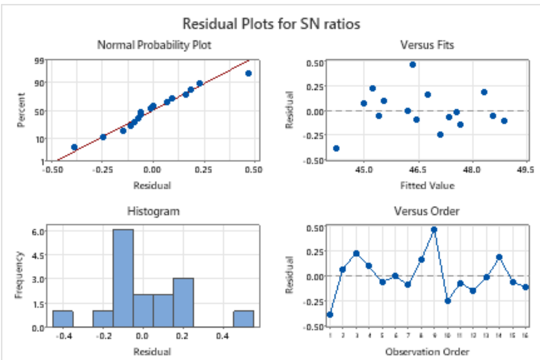

Fig 6.3: Residual plots for SN ratio

6.2.2 ANOVA analysis

A General Linear Model (GLM) analysis of variance (ANOVA) was performed using Minitab software to assess the impact of silica and boron fiber on Hybrid Metal Matrix Composites (HMMC). According to the ANOVA results, depicted in Figure 6.4, silica accounts for 85.81% of the variation, while boron fiber contributes 12.70%. The analysis also indicates that the differences in data are not statistically significant, leading to the acceptance of the null hypothesis, which suggests that there is no substantial difference in the effects of the two factors at the tested levels

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Si %	3	14953.0	85.81%	14953.0	4984.33	172.54	0.000
BF %	3	2213.7	12.70%	2213.7	737.89	25.54	0.000
Error	9	260.0	1.49%	260.0	28.89		
Total	15	17426.7	100.00%				

Figure 6.4 Analysis of variance result

6.2.3 ANN

The weights percentages for silica and boron fiber, alongside the tensile stress values from experimental measurements, have been verified through Artificial Neural Network (ANN) validation in MATLAB. Utilizing the Neural Net Fitting app, the data was partitioned into 75% for training, 20% for validation, and 5% for testing. The network was trained to achieve a low mean square error (MSE) value. The regression values for training, validation, and test data are approximately 1, indicating minimal error in the data set. Figure 6.5 highlights the optimal validation performance at epoch 7 with a performance value of 94.5365. The error histogram with 20 bins, as shown in Figure 6.6, displays an error range from -3 to +14.53, which is within the acceptable error assumptions. Finally, Figure 6.7 affirms that the data fits well within the expected range, with an overall regression value of 0.98783, suggesting a high level of accuracy in the neural network's predictive capability.

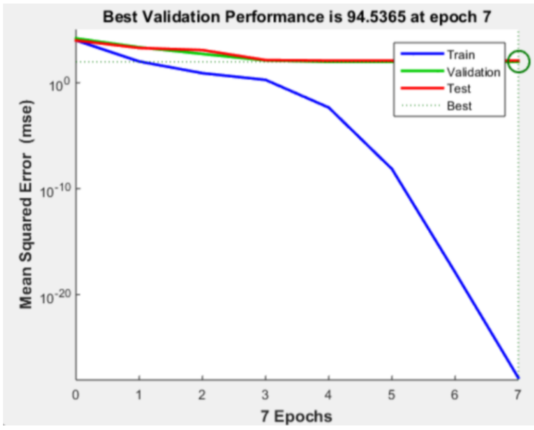

Fig 6.5: ANN validation performance.

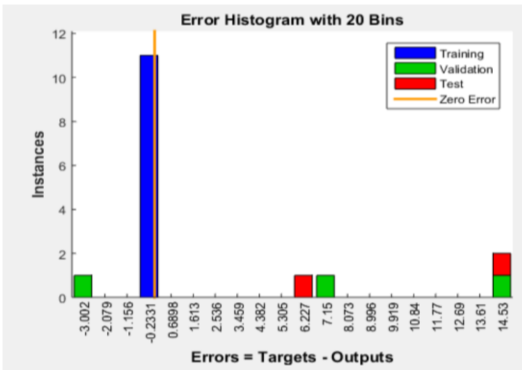

Fig 6.6: Error Histogram

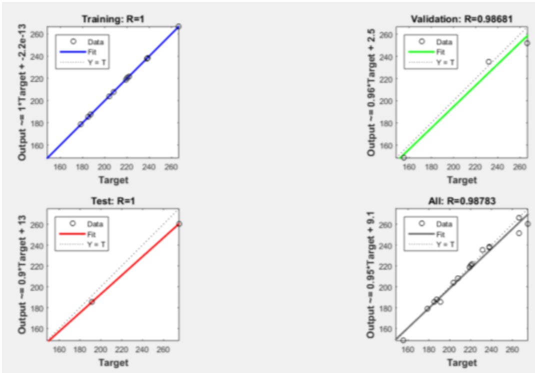

Fig 6.7: ANN Regression plots

6.2.4: Comparison of Experimental, Regression and ANN predicted value.

The tensile stress values measured through tensile testing, the regression values derived from the regression analysis formula in Minitab software (Tensile strength =159.58 +13.279 × Silica% +4.756 × Boron fiber %) and the predicted values from the Artificial Neural Network (ANN) across all variations of the metal matrix were compiled and contrasted, as depicted in Figure 6.8. This comparison indicates that the experimental values, regression values, and ANN predictions closely align within a similar data range.

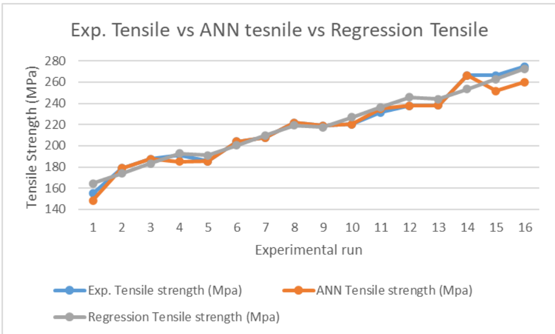

Fig 6.8: Comparison of Experimental result, Regression and ANN predicted values

7. Conclusion

The data presented in Figure 3 allows for the conclusion that incorporating boron fiber into the Aluminium 7075 matrix composite enhances its tensile strength. An increase in boron fiber content from 1% to 7% results in a general uptick in tensile strength, with the 5% to 7% range showing a plateau, suggesting a saturation point in tensile stress improvement. Additionally, the presence of silica further augments tensile strength. An optimal enhancement of 43.5% in tensile strength is observed with 6% silica and 7% boron fiber, indicating the most effective combination for reinforcing the composite.

The Taguchi model's R-square value of 97.87% points to a normal distribution of experimental values. The General Linear Model (GLM) ANOVA suggests no significant statistical difference, affirming the null hypothesis. ANN validation corroborates the experimental findings, with the best validation performance at epoch 7 and an Error Histogram across 20 bins showing a permissible error range from -3 to +14.53. An overall regression value of 0.98783 indicates minimal error, further validating the experimental results. The close correlation among experimental, regression, and ANN values across the dataset confirms the analyses are robust, errors are minimal, and the data distribution is normal.

In essence, silica's role in the composite material is to enhance the reinforcement effect provided by boron fiber, acting as a filler to bolster mechanical properties such as strength, stiffness, and stability. The synergistic combination of boron fiber and silica in the composite yields a material with superior performance characteristics.

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