CHAPTER 4

RESULT AND DISCUSSION

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4.0 Introduction

This chapter describes the analysis of various properties of the prepared samples which have been obtained using the appropriate equipment in the standard testing condition. Results obtained from the various tests mentioned in Chapter 3 are compiled and discussed herewith, for their application in various areas. In line with Chapter 3, this chapter is also divided into two sections. Section 1 deals with the analysis and comparison of results obtained from yarn and prepared triaxial braided rope with individual raw material and their different combinations. Section 2 deals with the analysis and comparison of results obtained from prepared braided composite rods with individual raw material and their different combinations.

For better understanding, Table 4.1 exhibits the experimental design which gives information regarding the materials used, their combinations, the number of samples prepared and different tests conducted. In totality, 235 tests were performed on 25 different combinations of ropes and rods each.

Table 4.1 Experimental design

<table>
<tr><th>Independent variables</th><th>Dependent Variables</th><td rowspan="12">BCRs were prepared using individual raw material for 5 different layers making total 25 combinations. Analysis was conducted starting for yarn, rope and rod and further analysed for different combinations.</td><th>Analysis</th><th>Characteristics</th></tr>
<tr><td rowspan="5">Raw material</td><td>PP</td><td rowspan="2">Yarn</td><td>Linear Density</td></tr>
<tr><td>Nylon</td><td>Mechanical Properties</td></tr>
<tr><td>Basalt</td><td rowspan="4">Rope</td><td>Linear Density</td></tr>
<tr><td>PP: Basalt</td><td>Mechanical Properties</td></tr>
<tr><td>Nylon: Basalt</td><td>Braid parameters</td></tr>
<tr><td rowspan="6">Layers</td><td rowspan="2">First</td><td>Blend analysis</td></tr>
<tr><td rowspan="5">Rod</td><td>Linear Density</td></tr>
<tr><td>Second</td><td>Fibre Volume Fraction</td></tr>
<tr><td>Third</td><td>Mechanical Properties</td></tr>
<tr><td>Fourth</td><td>Bond characteristics</td></tr>
<tr><td>Fifth</td><td>Flexural strength</td></tr>
</table>

4.1 Characterization

4.1.1 FTIR Spectroscopy for Resin

Figure 4.1 displays FTIR spectra of epoxy resin. The X-Axis indicates wavenumbers (cm-1) ranging between 4000 cm-1 to 400 cm-1 and the Y-Axis indicates transmittance (%T). The presence of bands at 862.74 cm-1 and 915.15 cm-1 (both C-O deformation) corresponds to epoxide ring vibrations, 1246.97 cm-1 correspond to asymmetrical C-O. Stretching vibration of C-C in aromatic rings appeared at 1510.41 cm-1. Narrow peak between 2900 cm-1 to 3000 cm-1 represent asymmetrical C-H stretch of -CH3 group. The presence of broad band at 3493.45 cm-1 indicates the presence of -OH stretching. The presence of important functional groups of epoxy resin was verified according to its chemical structure.

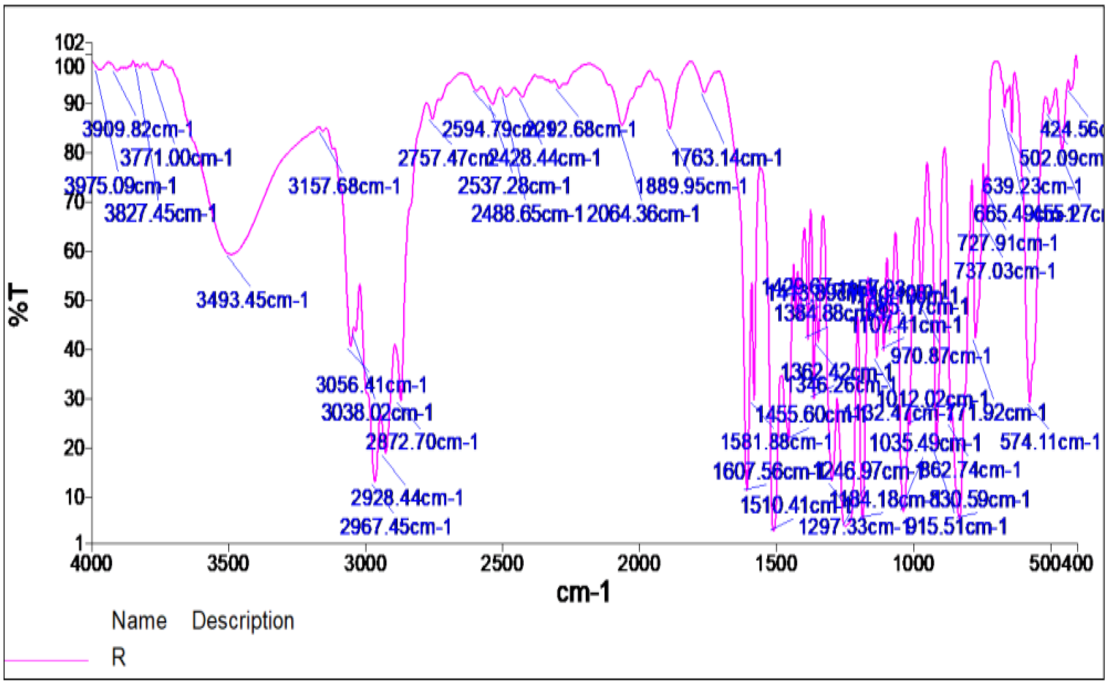

Figure 4.1 FTIR image for resin

4.1.2 FTIR Spectroscopy for Hardener

Figure 4.2 displays FTIR spectra of hardener for epoxy resin. The X-Axis indicates wavenumbers (cm-1) ranging between 4000 cm-1 to 400 cm-1 and the Y-Axis indicates transmittance (%T). The peak at 3368 cm-1corresponds to the stretching vibration of -NH group. Sharp Peaks at 2948 cm-1, and 2850 cm-1, represent the stretching vibrations of -CH bonds. Small Peak at 1869 cm-1 could be related to a carbonyl group (C=O). C=C Stretch (Small Peak near 1644 cm-1) indicates the presence of carbon-carbon double bonds (alkenes).

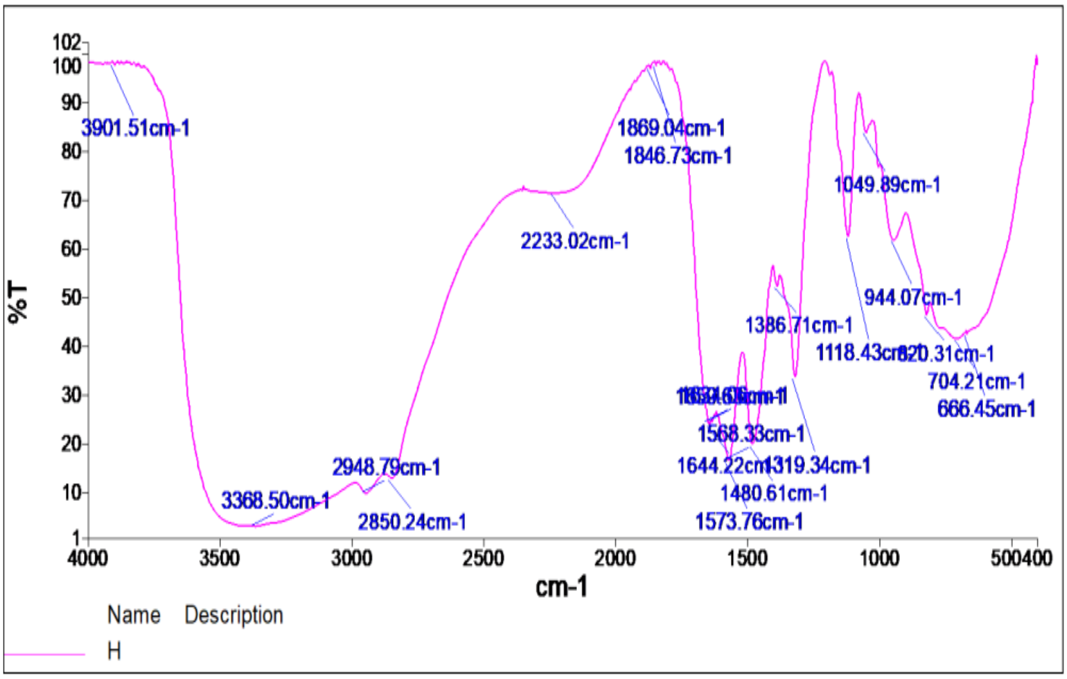

Figure 4.2 FTIR image for hardener

SECTION I

4.2 Yarn Properties

The yarn characteristics are important for choosing the right yarn for a particular application. Table 4.2 & Figure 4.3 provides information about different types of yarns procured and their test results. Basalt yarn has the maximum load-bearing capacity but a low extension & stress value, this may be due to the brittle nature of basalt fiber. Polypropylene has moderate values for both load and extension whereas nylon has high load-bearing capacity with maximum stress value but lower extension compared to PP. The selection of yarn was conducted based on high tenacity values suitable for required applications.

Table 4.2 Tensile properties of yarn

Sr.	Yarn type	Yarn count (Denier)	Maximum load (gf)	Maximum extension (mm)	Stress (gpd)	Strain (%)
1	Polypropylene	1500	9269.64	24.2972	6.179	24.29
2	Nylon	3550	25532	20.1558	7.192	20.15
3	Basalt	7200	33081.8	2.86894	4.594	2.87

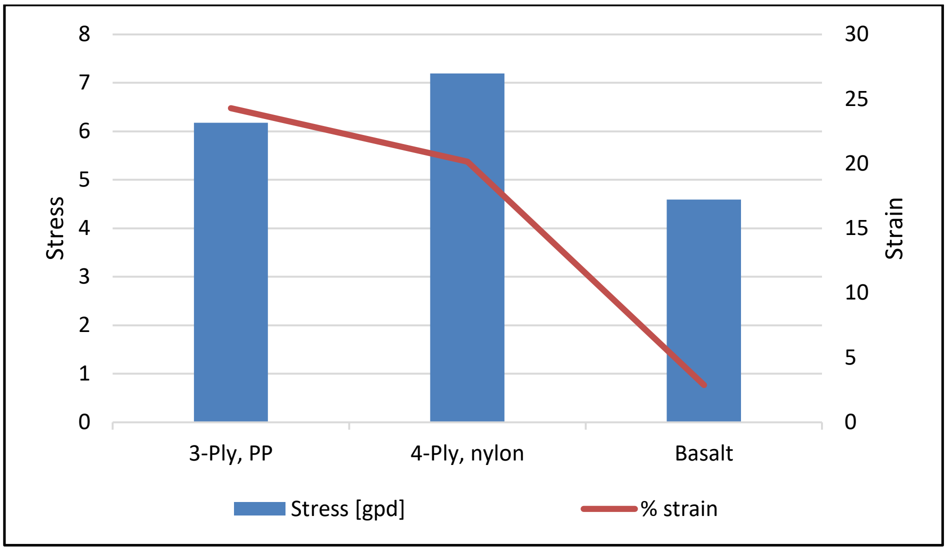

Figure 4.3 Yarn stress-strain analysis

4.3 Analysis of Braided Rope

Tri-axially braided ropes made from Basalt, PP, and Nylon & and their combinations (Figure 4.4) are discussed here for their linear density and tensile characteristics. Further, their comparison is made with relevant fiber, yarn, and its strength characteristics.

4.3.1 Linear Density

Linear density is a measure of mass per unit length which is an important parameter in braided composite rods. Table 4.3 represents the linear density of various ropes across multiple layers, where 100% basalt ropes represent higher linear density due to higher density of basalt fiber i.e., 2.53 g/cc.

Table 4.3 Braided rope linear density

Layer	Material linear density in grams/ linear meter				
	PP	Nylon	Basalt	PP + Basalt [35:65]	Nylon+ Basalt [50:50]
1	4.38	10.49	19.73	11.3	12.85
2	8.62	20.82	39.74	19.9	23.5
3	13.06	31.47	58.57	28.5	35
4	17.19	42.49	81.27	39	45.65
5	21.51	52.98	93.97	51.5	58.25

Basalt ropes are being followed by basalt- nylon blended ropes as it consists of 50% of basalt yarn and 50% of nylon yarn. Nylon ropes stand in third position as nylon fibres possess a density of 1.14 g/cc which is higher than PP but lower than basalt. This is being followed by a PP-basalt blend and 100% pp braided ropes as PP has the lowest fibre density of 0.91 g/cc. Table 4.3 Material linear density in Grams/ Linear Meter for different layers All materials exhibit a similar increase in linear density across layers, except for a minor difference in the increased pattern of basalt composition. It suggests an accumulation of mass per unit length with the addition of each layer.

Polypropylene

Nylon

Basalt

PP : Basalt

Nylon : Basalt

Figure 4.4 Prepared braided ropes with different material

4.3.2 Comparison of Tensile Properties: Between Layers

Figure 4.5 Tensile testing for rope prepared from different material

4.3.2.1 Polypropylene braided rope

The tensile test results for Polypropylene (PP) braided ropes, as presented in Table 4.4, indicate a clear trend of increasing maximum force and rope g/lm with each successive layer, while the maximum displacement remains relatively consistent. Starting with the first layer, the rope could withstand a force of 513.30 Kgf with the extension of 64.55 mm, and to the fifth layer which exhibits a significant jump in the maximum force of 1051.51 Kgf with a displacement of 68.25 mm. Figure 4.6 combines bar and line graph which exhibit percentage increments in tensile strength of prepared PP ropes with different layers.

Table 4.4 Tensile properties of polypropylene braided ropes

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	PP	First	513.30	64.55	4.38
2	PP	Second	627.92	66.52	8.62
3	PP	Third	682.74	67.11	13.06
4	PP	Fourth	742.54	68.75	17.19
5	PP	Fifth	1051.51	68.25	21.51

It can be observed that with an increase in the number of layers, the strength percentage increases as well as the g/lm value also increases. The graph suggests a linear increment in terms of tensile strength and g/lm with the increase in layers. Considering the first layer as 100%, it is observed that the subsequent layers increase by 122.33, 133.01, 144.66, and 204.85 respectively from the second to fifth layer.

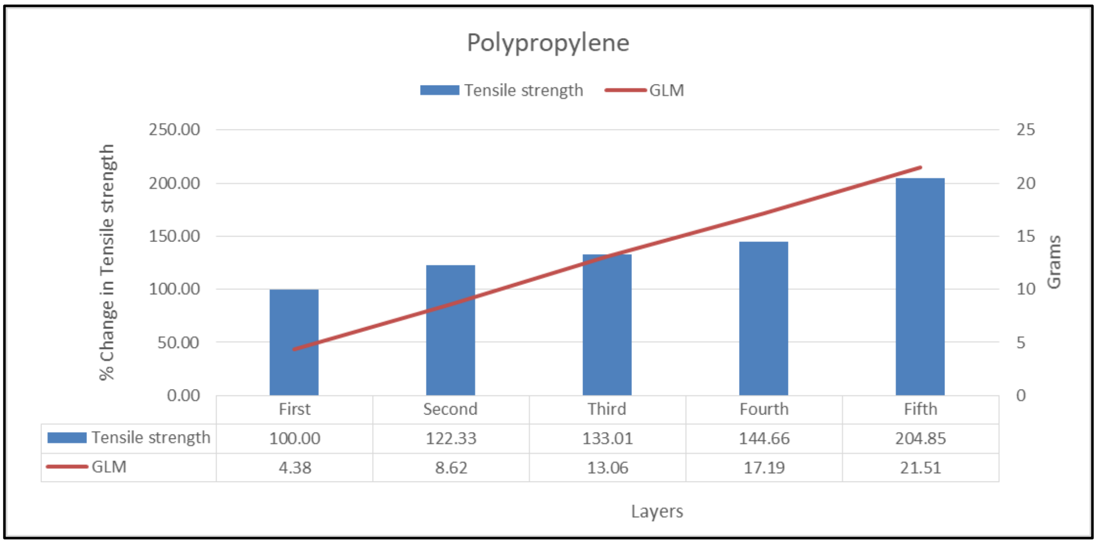

Figure 4.6 Percentage change in tensile strength

This data suggests that as the number of layers in PP braided ropes increases, the rope's ability to handle greater force, which is reflected in the rising rope g/lm values. The consistent displacement values suggest that the material maintains a stable elongation under stress across all layers. These characteristics are crucial for applications where ropes are expected to sustain heavy loads without significant stretching.

4.3.2.2 Nylon braided rope

The tensile test results for nylon braided ropes, as shown in Table 4.5, reveal a consistent increase in maximum force and rope g/lm with each additional layer, while the maximum displacement exhibits a slight fluctuation. The first layer of nylon rope withstands a maximum force of 657.82 Kgf, stretching to 53.79 mm, and has a rope g/lm of 10.49 to the fifth layer which demonstrates a substantial increase in maximum force of 1392.05 Kgf with the displacement of 50.30 mm. Figure 4.7 combines bar and line graphs which exhibit percentage increments in tensile strength of prepared nylon ropes with different layers. It can be observed that with an increase in the number of layers, the strength percentage increases, as well as the g/lm value, also increases. The graph suggests a linear increment in terms of tensile strength and g/lm with the increase in layers. Considering the first layer as 100%, it is observed that the subsequent layers increase by 143.94, 163.13, 175.25, and 211.62 respectively from the second to fifth layer.

Table 4.5 Tensile properties of nylon braided ropes

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	Nylon	First	657.82	53.79	10.49
2	Nylon	Second	946.86	55.43	20.82
3	Nylon	Third	1073.11	56.92	31.47
4	Nylon	Fourth	1152.85	48.33	42.49
5	Nylon	Fifth	1392.05	50.30	52.98

These results indicate that nylon braided ropes significantly enhance their load-bearing capacity with each layer, as evidenced by the increasing rope g/lm values. There is a negligible difference in the maximum displacement values, which will not affect the performance of the material.

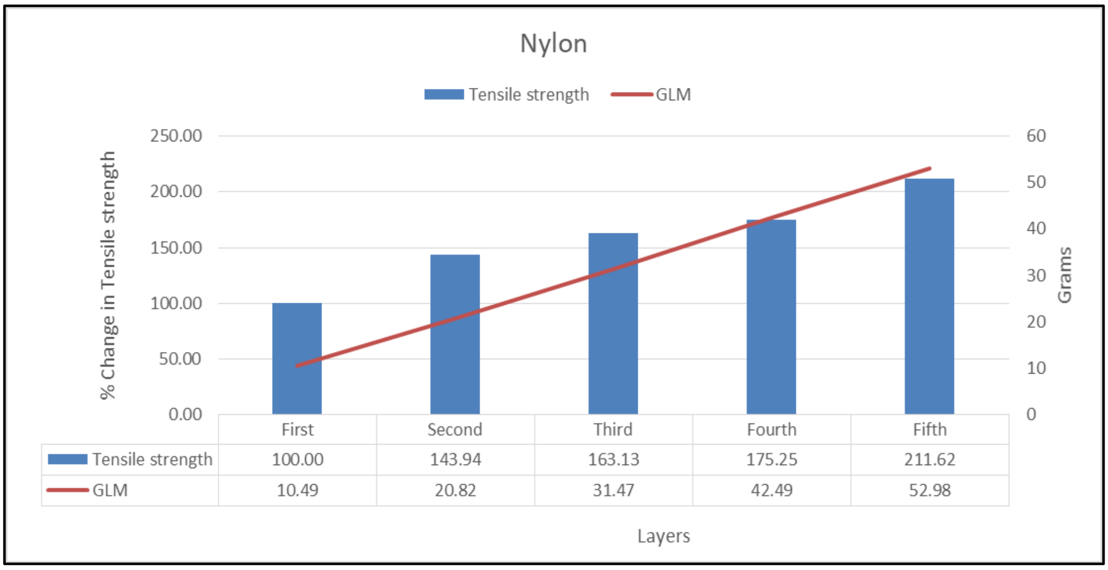

Figure 4.7 Percentage change in tensile strength

This data suggests that as the number of layers in Nylon braided ropes increases, the rope's ability to handle greater force, which is reflected in the rising rope g/lm values. The consistent displacement values suggest that the material maintains a stable elongation under stress across all layers. These characteristics are crucial for applications where ropes are expected to sustain heavy loads without significant stretching.

4.3.2.3 Basalt braided rope

The tensile test results for basalt braided ropes, as detailed in Table 4.6, demonstrate a progressive increase in maximum force and rope g/lm across the layers, with a notable consistency in maximum displacement. The first layer of basalt rope withstands a maximum force of 508.32 Kgf whereas the second, third, fourth, and fifth layer exhibits maximum force of 601.34, 900.35, 973.44, and 1073.11 kgf respectively.

Table 4.6 Tensile properties of basalt braided ropes

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	Basalt	First	508.32	5.38	19.73
2	Basalt	Second	601.34	5.54	39.74
3	Basalt	Third	900.35	5.09	58.57
4	Basalt	Fourth	973.44	5.26	81.27
5	Basalt	Fifth	1073.11	4.67	93.97

Figure 4.8 combines bar and line graphs which exhibit percentage increments in tensile strength of prepared Basalt ropes with different layers. It can be observed that with an increase in the number of layers, the strength percentage increases, as well as the g/lm value, also increases. The graph suggests a linear increment in terms of tensile strength and g/lm with the increase in layers. The consistent growth in rope g/lm values highlights the ropes' enhanced performance with each additional layer, affirming their suitability for heavy-duty usage where strength and stability are paramount. This data suggests basalt braided ropes exhibit outstanding tensile properties, making them a reliable choice for strenuous tasks.

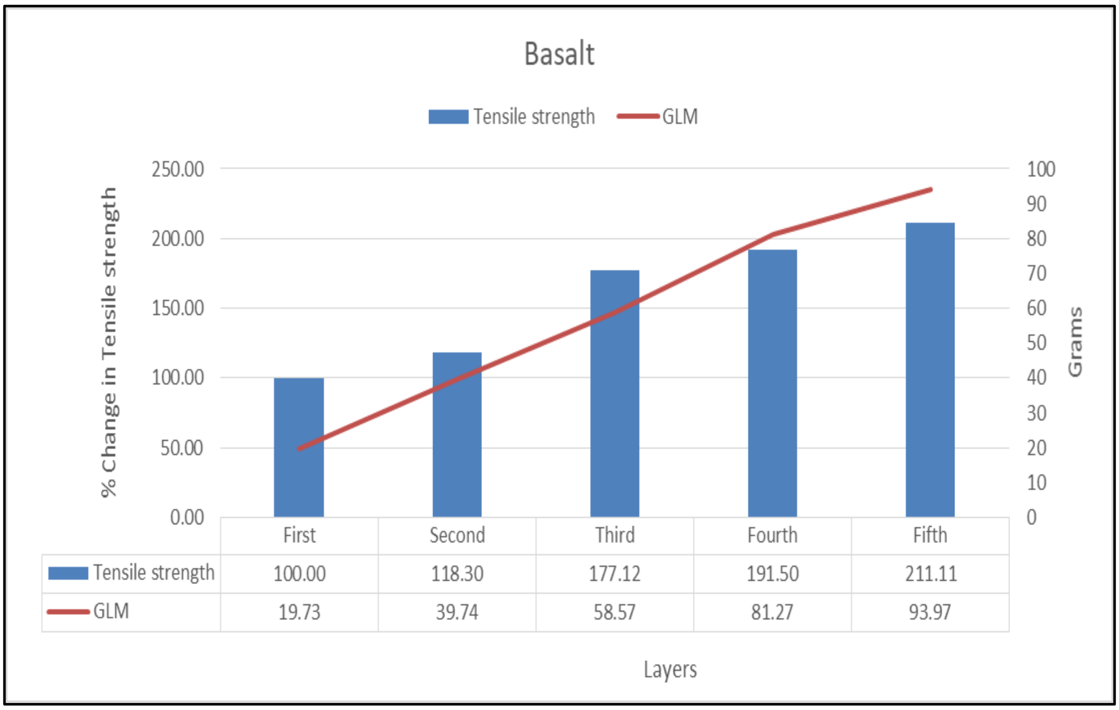

Figure 4.8 Percentage change in tensile strength

4.3.2.4 PP + basalt braided rope

The tensile test results for PP + basalt blended braided ropes, as shown in Table 4.7, demonstrate a progressive increase in maximum force and rope g/lm across the layers, with a notable consistency in maximum displacement. The first layer of PP + basalt rope withstands a maximum force of 621.27 Kgf whereas the second, third, fourth, and fifth layer exhibits maximum force of 631.24, 694.36, 863.80, and 847.19 kgf respectively. These blended ropes exhibit significant increments in the maximum displacement values which is much higher than 100% basalt ropes, which can be due to the higher maximum displacement values of 100% PP ropes.

Table 4.7 Tensile properties of polypropylene: basalt [35:65] braided ropes

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	PP + Basalt	First	621.27	18.83	11.30
2	PP + Basalt	Second	631.24	19.40	19.90
3	PP + Basalt	Third	694.36	18.82	28.50
4	PP + Basalt	Fourth	863.80	20.31	39.00
5	PP + Basalt	Fifth	847.19	21.80	51.50

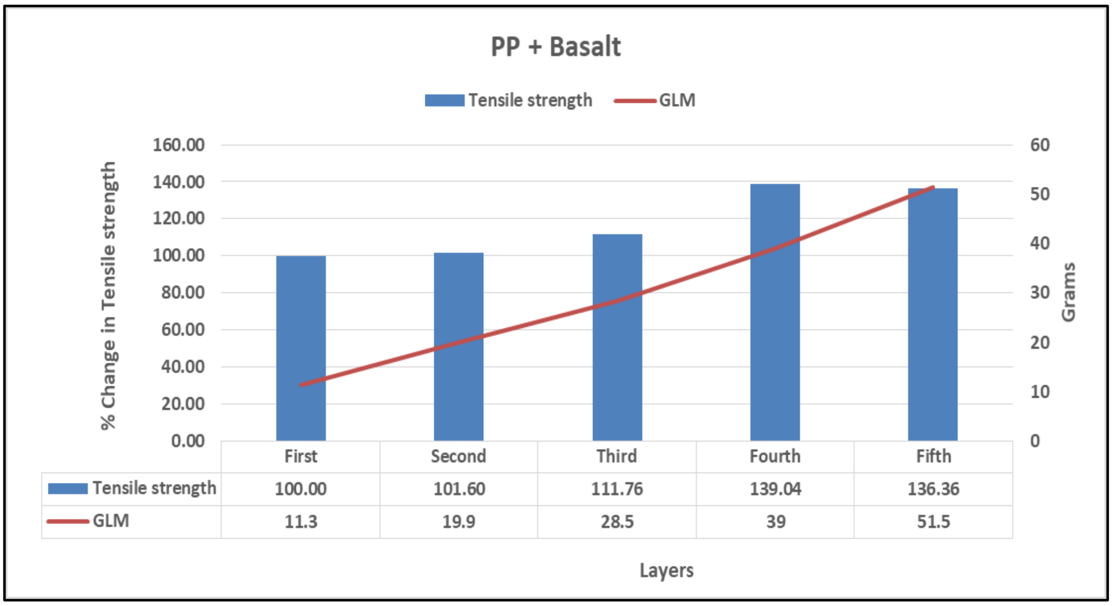

Figure 4.9 Percentage change in tensile strength

Figure 4.9 combines bar and line graphs which exhibit percentage increment in tensile strength of prepared PP + Basalt ropes with different layers. It can be observed that with the increase in the number of layers, the strength percentage increases, as well as the g/lm value, also increases. The graph suggests a linear increment in terms of tensile strength and g/lm with the increase in layers. It can be further analysed from the graph that the percentage increase in the load-bearing capacity of the prepared blend sample is not much as compared to individual PP and basalt ropes. This may be due to less inter-fiber friction between pp and basalt yarn which leads to lesser values of maximum force.

Overall, the data suggests variations in both force and displacement across layers, highlighting the material's performance under different conditions and aiding in informed decision-making for different structural applications in terms of mechanical properties and cost.

4.3.2.5 Nylon + basalt braided rope

The tensile test results for Nylon + basalt blended braided ropes, as shown in Table 4.8, demonstrate a progressive increase in maximum force and rope g/lm across the layers, with a notable consistency in maximum displacement. The first layer of Nylon + basalt rope withstands a maximum force of 523.27 Kgf whereas the second, third, fourth and fifth layer exhibits maximum force of 593.03, 694.36, 867.13 and 1003.34 kgf respectively. These blended ropes exhibit significant increments in the maximum displacement values which is much higher than 100% basalt ropes, which can be attributed to higher maximum displacement values of 100% Nylon ropes.

Table 4.8 Tensile properties of nylon: basalt [50:50] braided ropes

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	Nylon + Basalt	First	523.27	16.14	12.85
2	Nylon + Basalt	Second	593.03	16.63	23.50
3	Nylon + Basalt	Third	694.36	15.28	35.00
4	Nylon + Basalt	Fourth	867.13	15.86	45.65
5	Nylon + Basalt	Fifth	1003.34	15.41	58.25

Figure 4.10 combines bar and line graphs which exhibit percentage increment in tensile strength of prepared Nylon + Basalt braided ropes with different layers. It can be observed that with the increase in the number of layers, the strength percentage increases, as well as the g/lm value, also increases. The graph suggests a linear increment in terms of tensile strength and g/lm with the increase in layers. It can be further analyzed from the graph that the percentage increase in the load-bearing capacity of the prepared blend sample is not much as compared to individual nylon and basalt ropes. This may be due to less inter-fibre friction between nylon and basalt yarn which leads to lesser values of maximum force.

Overall, the material demonstrates progressively higher force capabilities across layers, while maintaining a moderate level of displacement. This information aids in understanding the material's performance characteristics in various structural applications, facilitating informed decision-making for different structural applications in terms of mechanical properties and cost.

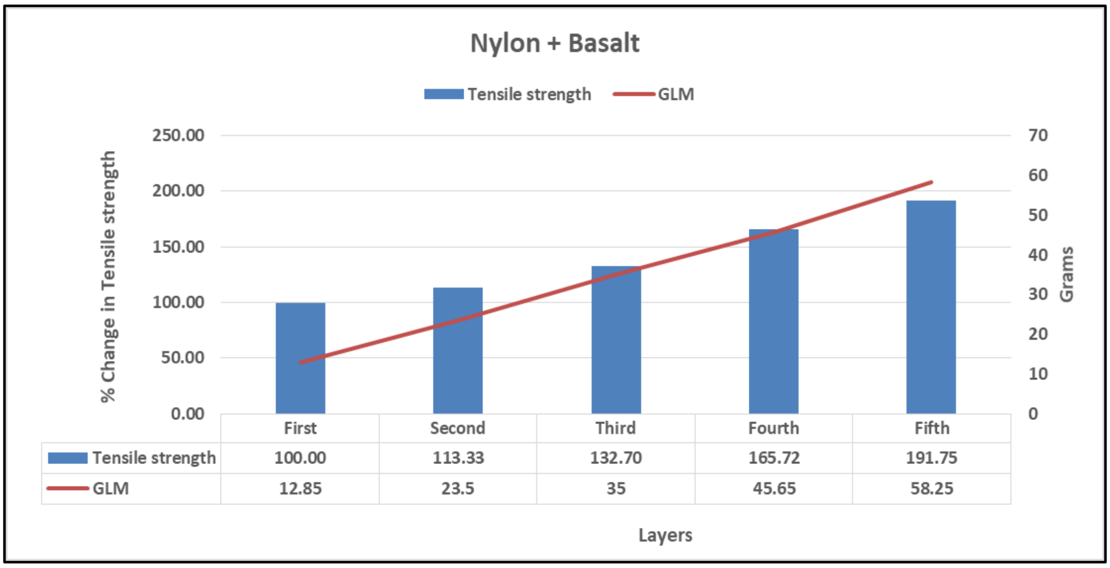

Figure 4.10 Percentage change in tensile strength

4.3.3 Comparison of Tensile properties: Within Layer

4.3.3.1 First layer

The tensile test results for the first layer of braided ropes, as presented in Table 4.9 and Figure 4.11, reveal insights into the performance of different materials.

Table 4.9 Comparative tensile behavior of first layer for all material

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	PP	First	513.30	64.55	4.38
2	Nylon	First	657.82	53.79	10.49
3	Basalt	First	508.32	5.38	19.73
4	PP + Basalt [35:65]	First	621.27	18.83	11.30
5	Nylon + Basalt [50:50]	First	523.27	16.14	12.85

It can be observed that the Polypropylene (PP) rope exhibited a maximum force of

513.30 Kgf and a maximum displacement of 64.55 mm, at a Rope g/lm of 4.38. In contrast, the Nylon rope demonstrated superior strength with a maximum force of 657.82 Kgf, with a lesser displacement of 53.79 mm, at rope g/lm of 10.49. The Basalt rope, while having a comparable maximum force (508.32 Kgf) to the PP rope, had a significantly lower maximum displacement (5.38 mm), with the highest rope g/lm of 19.73 among the single-material ropes. When it comes to blended ropes, the PP + Basalt [35:65] rope showed a higher maximum force (621.27 Kgf) than the single-material ropes and a moderate displacement (18.83 mm), at a Rope g/lm of 11.30. The Nylon + Basalt [50:50] rope, on the other hand, had a maximum force (523.27 Kgf) similar to the PP and Basalt ropes but a lower displacement (16.14 mm), at a Rope g/lm of 12.85.

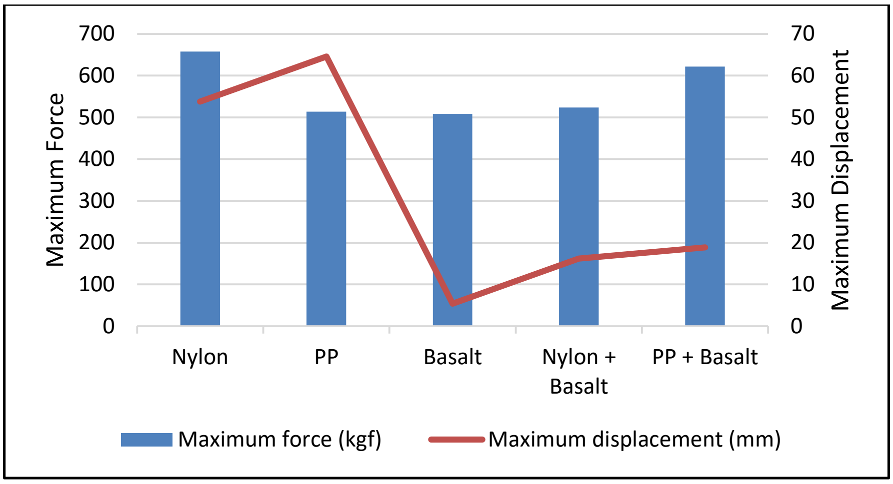

Figure 4.11 Stress-strain behaviour of first layer

Low maximum force in basalt rope can be possibly due to the brittleness of the fibres which may have broken during rope preparation as well as material handling. Figure 4.11 helps in understanding which material or combination of materials might be best suited for applications requiring specific mechanical properties. For instance, if high force resistance is needed with low displacement, PP + Basalt [35:65] might be a good choice. If only high force resistance is needed regardless of displacement, nylon could be considered.

4.3.3.2 Second layer

The tensile test results for the second layer of braided ropes, as shown in Table 4.10 and Figure 4.12, provide a comparative analysis of the performance of different materials. The Polypropylene (PP) rope in the second layer demonstrated a maximum force of 627.92 Kgf and a maximum displacement of 66.52 mm, with a Rope g/lm of 8.62. The Nylon rope showed a significant increase in strength with a maximum force of 946.86 Kgf and a displacement of 55.43 mm, at a high Rope g/lm of 20.82. The Basalt rope, while having a maximum force (601.34 Kgf) similar to the PP rope, had a much lower maximum displacement (5.54 mm), with impressive Rope g/lm of 39.74.

Table 4.10 Comparative tensile behavior of second layer for all material

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	PP	Second	627.92	66.52	8.62
2	Nylon	Second	946.86	55.43	20.82
3	Basalt	Second	601.34	5.54	39.74
4	PP + Basalt [35:65]	Second	631.24	19.40	19.90
5	Nylon + Basalt [50:50]	Second	593.03	16.63	23.50

For the composite ropes, the PP + Basalt [35:65] rope showed a slight increase in maximum force (631.24 Kgf) compared to the single-material ropes and a moderate displacement (19.40 mm), with a Rope g/lm of 19.90. The Nylon + Basalt [50:50] rope had a maximum force (593.03 Kgf) similar to the PP and Basalt ropes but a lower displacement, (16.63 mm), at a Rope g/lm of 23.50. This data can be useful for selecting materials based on the required mechanical properties for specific applications in the second layer of a structure.

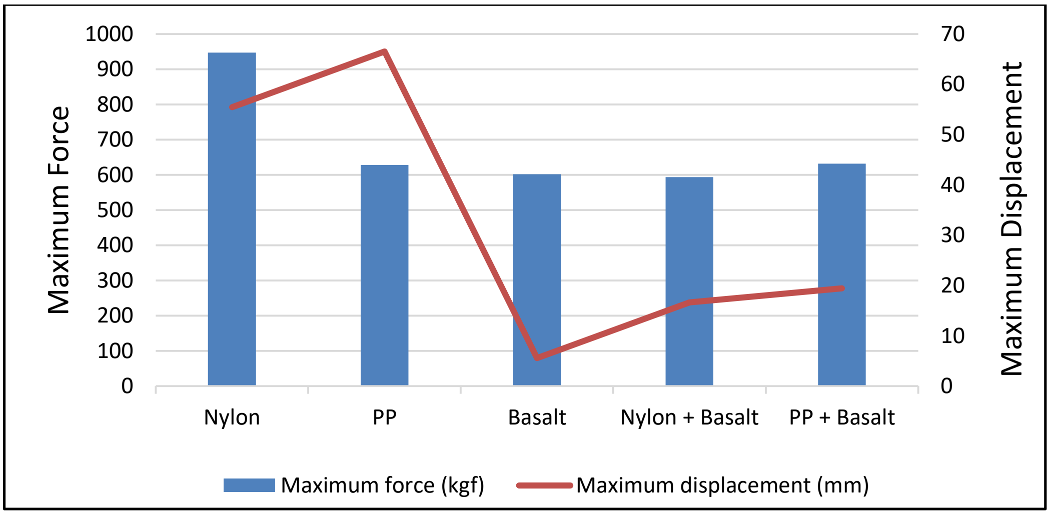

Figure 4.12 Stress-strain behaviour of second layer

4.3.3.3 Third layer

The tensile test results for the third layer of braided ropes, as presented in Table 4.11, reveal significant variations in performance among different materials. Figure 4.13 compares the maximum force and maximum displacement for different materials, helping in the selection of materials based on the required mechanical properties for specific applications in the third layer of a structure. Nylon in the third layer has the highest maximum force, making it suitable for applications requiring high strength, but it also has a high displacement. PP has the highest displacement, which might be a concern for applications requiring minimal deformation. Basalt has a high force and the lowest displacement, indicating it is strong and very stable. It should also be noted that as the number of layers increases in the basalt ropes the maximum load bearing capacity also increases compared to pp showing the impact of basalt fibre. Nylon + Basalt [50:50] and PP + Basalt [35:65] combinations offer a balance, with both having the same maximum force but different displacements, making them suitable for applications requiring moderate strength and low to moderate displacement.

Table 4.11 Comparative tensile behavior of third layer for all material

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	PP	Third	682.74	67.11	13.06
2	Nylon	Third	1073.11	56.92	31.47
3	Basalt	Third	900.35	5.09	58.57
4	PP + Basalt [35:65]	Third	694.36	18.82	28.50
5	Nylon + Basalt [50:50]	Third	694.36	15.28	35.00

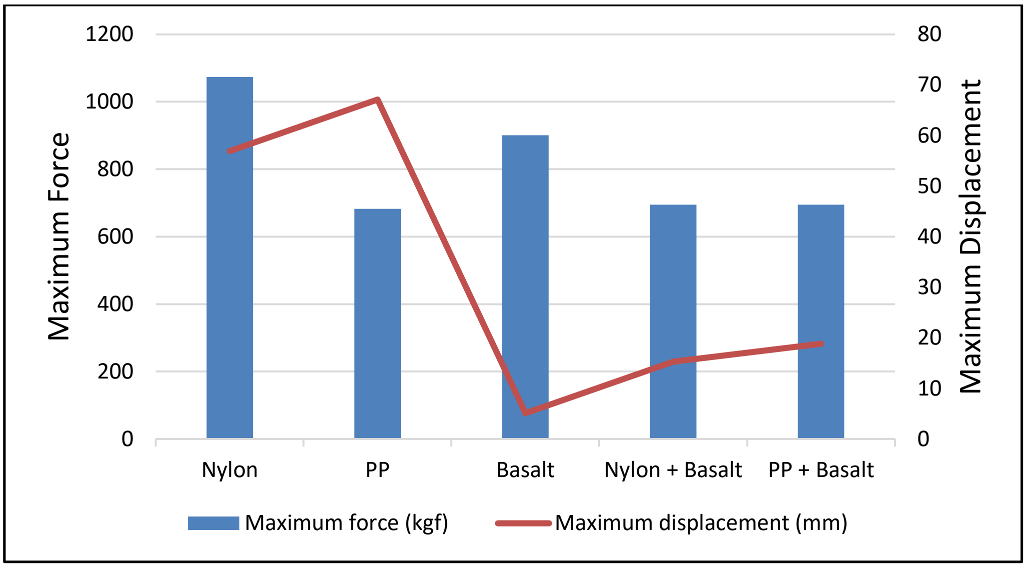

Figure 4.13 Stress-strain behaviour of third layer

4.3.3.4 Fourth layer

The tensile test results for the fourth layer of braided ropes is presented in Table 4.12 and Figure 4.14. It shows polypropylene (PP) ropes registered a maximum force of 742.54, nylon exhibited 1152.5 kgf, basalt 973.44 kgf. This suggests that Basalt ropes possess superior tensile strength and minimal elongation under load, making them highly efficient in terms of energy absorption and resistance to stretching. The blend of PP + Basalt [35:65] and Nylon + Basalt [50:50] shows maximum force of 863.80 Kgf and 867.13 Kgf respectively. These results suggest that the integration of Basalt fibres into PP and Nylon ropes enhances their overall tensile properties, offering a compromise between strength and elasticity.

Table 4.12 Comparative tensile behavior of fourth layer for all material

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	PP	Fourth	742.54	68.75	17.19
2	Nylon	Fourth	1152.85	48.33	42.49
3	Basalt	Fourth	973.44	5.26	81.27
4	PP + Basalt [35:65]	Fourth	863.80	20.31	39.00
5	Nylon + Basalt [50:50]	Fourth	867.13	15.86	45.65

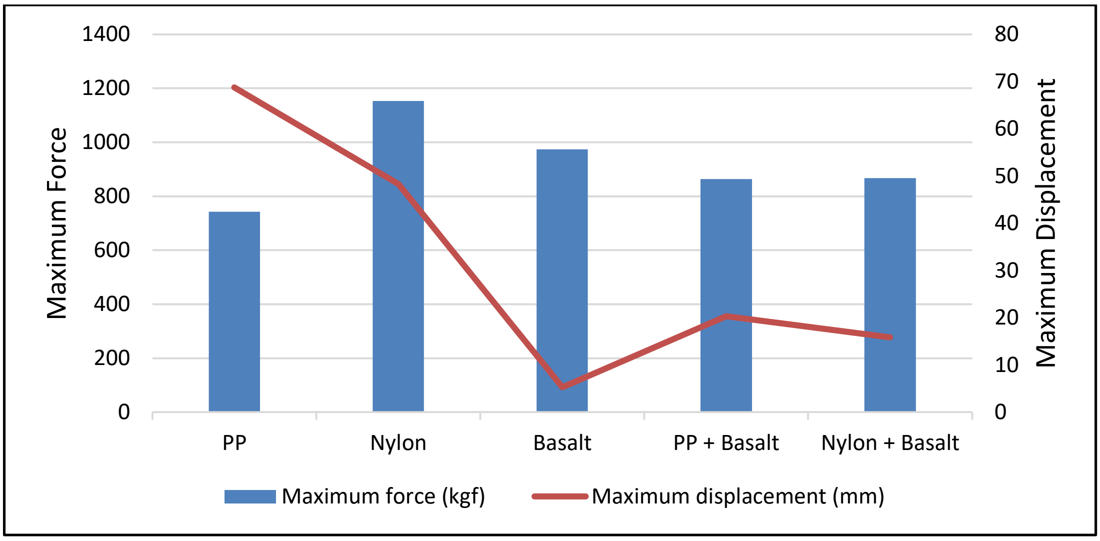

Figure 4.14 Stress-strain behaviour of fourth layer

4.3.3.5 Fifth layer

The tensile test results for the fifth layer of braided ropes, presented in Table 4.13 & Figure 4.15, reveal a distinct performance profile for each material tested. The Polypropylene (PP) ropes showed a maximum force of 1051.51 Kgf and a displacement of 68.25 mm. The Nylon ropes, on the other hand, exhibited a higher maximum force of 1392.05 Kgf and a lower displacement of 50.30 mm.

Table 4.13 Comparative tensile behavior of fifth layer for all material

Sr. No	Material	Layer number	Maximum force (Kgf)	Maximum displacement (mm)	Rope g/lm
1	PP	Fifth	1051.51	68.25	21.51
2	Nylon	Fifth	1392.05	50.30	52.98
3	Basalt	Fifth	1073.11	4.67	93.97
4	PP + Basalt [35:65]	Fifth	847.19	21.80	51.50
5	Nylon + Basalt [50:50]	Fifth	1003.34	15.41	58.25

The Basalt ropes stood out with a maximum force of 1073.11 Kgf and a minimal displacement of 4.67 mm. This indicates that Basalt ropes have exceptional tensile strength and very little elongation when subjected to force, which is advantageous for applications where high load-bearing capacity and minimal stretch are desired. The PP and Basalt blend recorded a maximum force of 847.19 Kgf, a displacement of 21.80 mm. Whereas, the Nylon and Basalt blend showed a maximum force of 1003.34 Kgf, a displacement of 15.41 mm.

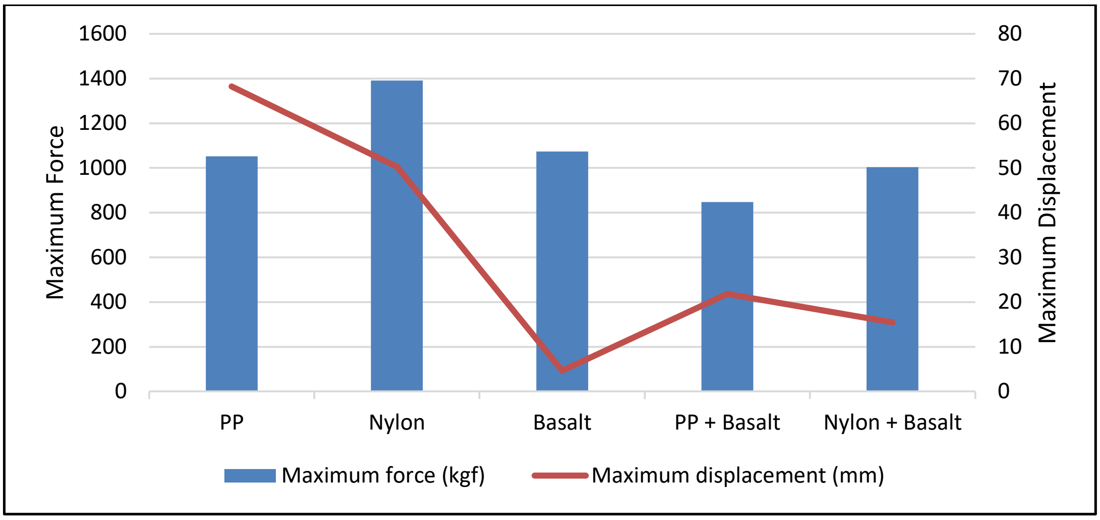

Figure 4.15 Stress-strain behaviour of fifth layer

<u>Section II</u>

Analyzing the physical specifications of braided rods for varying diameters and materials is essential for engineers across industries. This analysis helps in understanding mechanical properties like tensile strength and elasticity, ensuring durability and reliability while optimizing performance for specific applications. It helps for cost-effective decisions by balancing performance requirements with budget constraints and enables customization for specific applications. Moreover, it ensures safety and compliance with industry standards, crucial in sectors like civil engineering. Finally, this analysis empowers engineers to design, manufacture, and use braided rods effectively, considering factors such as mechanical properties, cost, safety, and performance optimization.

4.4 Fiber Volume Fraction Analysis

Fiber Volume Fraction is a measure of how much fiber is in a composite material. It is a ratio that tells you the amount of fiber compared to the total volume of the composite. The amount of fiber in the composite affects its mechanical properties like strength and stiffness. More fiber can make the composite stronger and stiffer. So, by changing the fiber volume fraction, we can adjust these properties. The fiber volume fraction also helps maintain a good balance between the fiber and the resin or polymer.

Polypropylene BCR

Nylon BCR

Basalt BCR

PP Basalt BCR

Nylon Basalt BCR

Figure 4.16 Braided Composite rods prepared from various materials

This balance is important for the composite to perform well. Because fibers are long and cylindrical, they can make the composite stronger in the direction they're laid. By changing the fiber volume fraction and the way the composite is made, we can customize its properties to suit different needs. This makes composite materials very versatile and suitable for a wide range of applications. The fiber volume fraction plays a pivotal role in determining the performance and application of textile composites. It allows for the customization of the composite material's properties, making it suitable for a wide range of applications.

4.4.1 Polypropylene BCR

Table 4.14 illustrates the fiber volume fraction across different layers of polypropylene (PP) material. The table details the composition of each layer, including measurements of rope in grams per linear meter, resin content, rod content, and the volume fraction of fibers. In the initial layer, the fiber volume fraction is 0.41, indicating that fibers constitute approximately 41%. The composition of this layer is balanced, with a notable presence of resin in rod. As we progress to the second layer, there's an increase in rope content, leading to a higher fiber volume fraction of 0.52. This increase suggests an enhancement in fiber reinforcement, which likely contributes to improved mechanical properties. Layer 3 stands out with the highest fiber volume fraction of 0.54, indicating optimal fiber integration. The equilibrium among rope, resin, and rod elements in this layer contributes to the material's rigidity and strength.

However, beyond layer 3, there is a slight decrease in the fiber volume fraction. Despite having higher rope content, layers 4 and 5 exhibit lower fiber fractions, suggesting a point of diminishing returns in terms of reinforcement. It fluctuates across layers, suggesting that other factors such as fiber arrangement or distribution influence the efficiency of fiber utilization. It appears that beyond a certain threshold, the penetration of more resin is becoming more difficult. Data Table 4.14 suggests here the key to optimizing the performance of a material like PP lies in achieving the perfect balance of fiber content. While layer 3 showcases the highest volume fraction of fibers, layers 4 and 5 demonstrate diminishing returns. This information is invaluable for engineers and designers as they can leverage it to customize material compositions for specific applications, keeping in mind both strength and cost-effectiveness.

Table 4.14 Fiber volume fraction in polypropylene BCR

Material	Layer	Rope g/lm	Resin g/lm	Rod g/lm	Fiber Volume Fraction
PP	1	4.38	8.50	12.88	0.41
PP	2	8.62	10.80	19.42	0.52
PP	3	13.06	15.21	28.27	0.54
PP	4	17.19	24.05	41.24	0.50
PP	5	21.51	36.49	58.00	0.45

4.4.2 Nylon BCR

Table 4.15 provides insights into the fiber volume fraction across different layers of nylon material. The first layer shows a high fiber volume fraction of 0.85, suggesting that fibers make up approximately 85% of the material. This may be due to application of high-pressure during manufacturing process being a hand lay-up method. Transitioning to the second layer, there is an increase in rope content, but the fiber volume fraction drops to 0.59. This layer achieves a balance between reinforcement and resin content. Layer 3 sustains a moderate fiber volume fraction of 0.54. With a higher resin content of 29.72 g/lm, this layer suggests a more balanced composite.

In the fourth and fifth layers, the rope content continues its upward trend, leading to a marginal increase in the fiber volume fraction. These layers follow a similar pattern to layer 2, emphasizing reinforcement. This information allows engineers to customize material compositions based on specific needs, taking into account factors like strength, stiffness, and cost-effectiveness.

Table 4.15 Fiber volume fraction in nylon BCR

Material	Layer	Rope g/lm	Resin g/lm	Rod g/lm	Fiber Volume Fraction
Nylon	1	10.49	2.08	12.57	0.85
Nylon	2	20.82	16.00	36.82	0.59
Nylon	3	31.47	29.72	61.19	0.54
Nylon	4	42.49	31.76	74.25	0.59
Nylon	5	52.98	31.42	84.4	0.65

4.4.3 Basalt BCR

Result Table 4.16 illustrates the fiber volume fraction in various layers of basalt material. The first layer has a fiber volume fraction of 0.48, signifying that fibers constitute about 48% of the material. The balanced composition of this layer is indicated by the moderate rope content and a significant amount of resin and rod. The second layer sees an increase in rope content, leading to a rise in the fiber volume fraction to 0.52. This layer is characterized by enhanced fiber reinforcement, which likely boosts its mechanical properties. Layer 3, on the other hand, has a lower fiber volume fraction of 0.46, possibly due to the higher resin and rod content.

In the fourth layer, a substantial increase in rope content results in the highest fiber volume fraction of 0.60. This layer showcases robust fiber reinforcement, which could potentially improve the material's strength. The fifth layer maintains a fairly high fiber volume fraction of 0.54, with the equilibrium between rope, resin, and rod components influencing the overall material properties.

To sum up, the performance of the basalt composite material hinges on the optimal balance of fiber content. Layers 2 and 4 display the highest fiber fractions, while layer 3 shows a slight deviation. This data can guide designers in customizing material compositions for specific uses, taking into account both strength and cost-effectiveness.

Table 4.16 Fiber volume fraction in basalt BCR

Material	Layer	Rope g/lm	Resin g/lm	Rod g/lm	Fiber Volume Fraction
Basalt	1	19.73	10.56	53.5	0.48
Basalt	2	39.74	18.14	45.63	0.52
Basalt	3	58.57	33.49	57.18	0.46
Basalt	4	81.27	27.33	33.63	0.60
Basalt	5	93.97	39.23	41.75	0.54

4.4.4 Polypropylene & Basalt BCR

Table 4.17 presents the fiber volume fraction for different layers of the PP + Basalt composite material. The first layer has a fiber volume fraction of 0.60, suggesting that fibers make up about 60% of the material. The balanced composition of this layer is indicated by the moderate rope content and a substantial amount of resin and rod. The second layer sees an increase in rope content, leading to a slight decrease in the fiber volume fraction to 0.53. This layer maintains a good equilibrium between reinforcement and resin content. Layer 3 shows an enhanced fiber volume fraction of 0.56, which can be attributed to the higher rope and rod content.

Table 4.17 Fiber volume fraction in polypropylene + basalt BCR

Material	Layer	Rope g/lm	Resin g/lm	Rod g/lm	Fiber Volume Fraction
PP + Basalt	1	11.30	4.83	16.13	0.60
PP + Basalt	2	19.90	11.37	31.27	0.53
PP + Basalt	3	28.50	14.56	43.06	0.56
PP + Basalt	4	39.00	21.63	60.63	0.53
PP + Basalt	5	51.50	24.64	76.14	0.57

In the fourth layer, despite the continued increase in rope content, the fiber volume fraction remains steady at 0.53. This layer achieves a balance between reinforcement and matrix components. The fifth layer maintains a relatively high fiber volume fraction of 0.57, with the harmony between rope, resin, and rod components influencing the overall material properties.

Data Table 4.17 suggests here the performance of the PP + Basalt composite material is contingent on finding the optimal balance of fiber content. Layers 1 and 5 represent the extremes, while layers 2, 3, and 4 find a middle ground. This information can guide designers in customizing material compositions for specific uses, taking into account both strength and cost-effectiveness.

4.4.5 Nylon & Basalt BCR

Table 4.18 illustrates the fiber volume fraction for different layers of the Nylon + Basalt composite material. The first layer has a fiber volume fraction of 0.49, suggesting that fibers constitute about 49% of the material. The balanced composition of this layer is indicated by the moderate rope content and a substantial amount of resin and rod. The second layer sees an increase in rope content, leading to a decrease in the fiber volume fraction to 0.43. This layer maintains a good equilibrium between reinforcement and resin content. Layer 3 shows an enhanced fiber volume fraction of 0.51, which can be attributed to the higher rope and rod content. In the fourth layer, despite the continued increase in rope content, the fiber volume fraction increases slightly to 0.52. This layer achieves a balance between reinforcement and matrix components. The fifth layer maintains a relatively high fiber volume fraction of 0.54, with the harmony between rope, resin, and rod components influencing the overall material properties.

Table 4.18 Fiber volume fraction in nylon + basalt BCR

Material	Layer	Rope g/lm	Resin g/lm	Rod g/lm	Fiber Volume Fraction
Nylon + Basalt	1	12.85	9.03	21.88	0.49
Nylon + Basalt	2	23.50	21.37	44.87	0.43
Nylon + Basalt	3	35.00	23.42	58.42	0.51
Nylon + Basalt	4	45.65	28.37	74.02	0.52
Nylon + Basalt	5	58.25	33.50	91.75	0.54

To sum up, it is observed from analysis fibre volume fraction analysis ranges between 40% - 65% which may help in increased load bearing capacity of prepared braided composite rods.

4.5 Tensile Properties of BCR

4.5.1 Comparison Between Layer

4.5.1.1 Polypropylene BCR

The data presented in Table 4.19 and Figure 4.17 offer a comprehensive view of the tensile properties of Polypropylene (PP) braided rods across five different layers. The initial layer features a rod diameter of 5.00 mm and an ultimate load capacity of 786.12 Kgf, which increases with an increase in rod diameter leading maximum strength of 1889.88 Kgf of the fifth layer with 7.84 mm rod diameter, which is evident that as diameter increases the rod strength increases.

Looking at the stress value of PP braided composite rods, it is observed from Table 4.19 and Figure 4.17 that as the diameter increases the load-bearing capacity of the PP braided composite rod decreases, this can be attributed to a larger diameter, the outer layers bear more load compared to the inner layers.

Table 4.19 Tensile properties of polypropylene BCR

Material	Layer number	Rod Dia. (mm)	Ultimate load (Kgf)	Stress (MPa)	Strain (%)	Modulus (GPa)
PP	First	5.00	786.12	392.96	31.09	21.74
PP	Second	5.50	994.22	410.73	23.21	20.65
PP	Third	7.00	1186.14	302.51	22.03	19.83
PP	Fourth	7.38	1347.87	309.27	21.46	19.14
PP	Fifth	7.84	1889.88	384.24	21.71	18.60

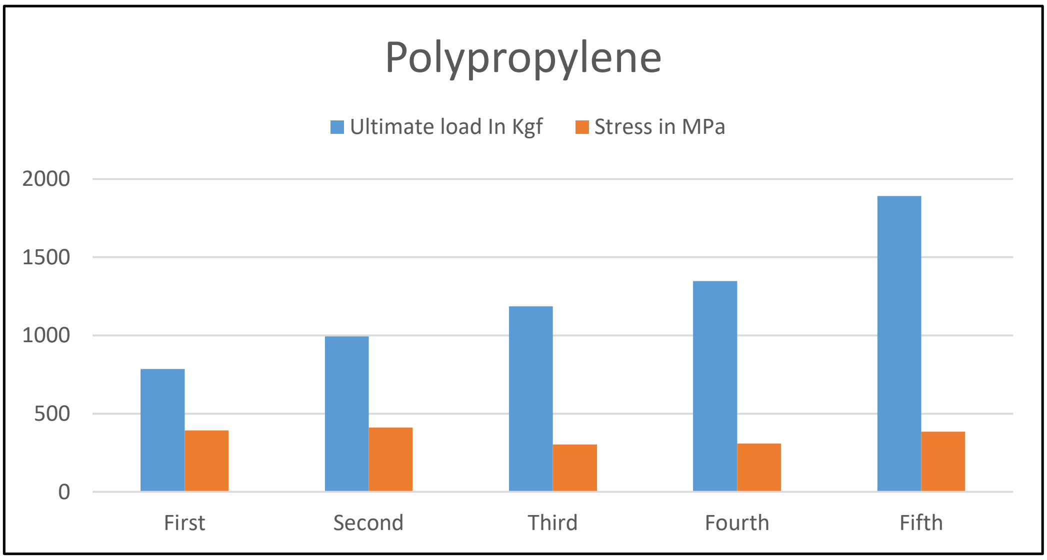

Figure 4.17 Comparison of ultimate load with stress

This uneven distribution can cause a reduction in the overall stress-bearing capacity of the rope as a composite structure. Apart from that larger diameter ropes experience higher shear forces between layers. These forces can cause slippage or deformation between layers, reducing the overall tensile strength. As seen from the figure 4.17, the stress value decreases from the first layer to the fourth layer but a sudden rise has been observed in the stress value for the fifth layer, this can be attributed to more concentric pressure as number of layer increases.

Figure 4.18 compares polypropylene braided rod for its strain percentage with modulus. The strain percentage is also crucial in steel rebars and braided composite rods. The strain percentage becomes more important for high-altitude buildings. The percentage strain of the prepared PP braided composite rods ranges from 21% to 31%, which is very well in the range defined by steel grade IS requirement of 10% to 23%. Apart from that modulus of the prepared rod also remains almost constant. This suggests that the material becomes stiffer and potentially more brittle with each successive layer, which could be a deliberate design choice to meet specific mechanical requirements in applications where higher load-bearing capacity and stiffness are desired.

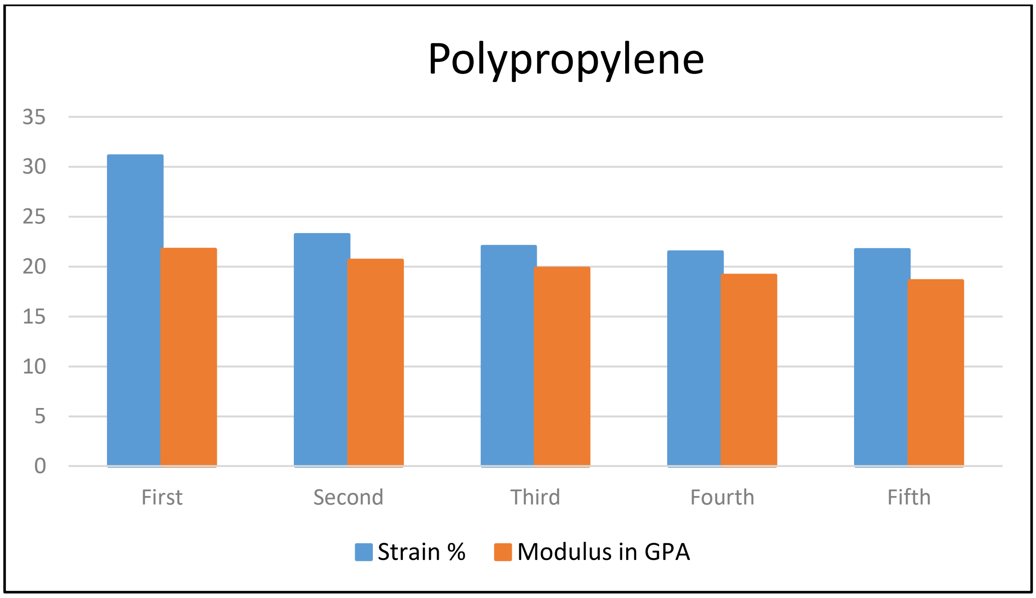

Figure 4.18 Comparison of strain % with modulus

(a) Marking before testing ***(b) Sample mounting***

Figure 4.19 Rod tensile testing process

4.5.1.2 Nylon BCR

The data presented in Table 4.20 and Figure 4.20 offers a comprehensive view of the tensile properties of Nylon braided rods across five different layers. The initial layer features a rod diameter of 4.25 mm and an ultimate load capacity of 1367.10 Kgf, which increases with an increase in rod diameter leading maximum strength of 2845.35 Kgf of the fifth layer with 9.17 mm rod diameter, which is evident that as diameter increases the rod strength increases.

Table 4.20 Tensile properties of nylon BCR

Material	**Layer number**	**Rod Dia. (mm)**	**Ultimate load (Kgf)**	**Stress (MPa)**	**Strain (%)**	**Modulus (GPa)**
Nylon	First	4.25	1367.10	945.85	22.12	19.44
Nylon	Second	7.00	1581.44	403.33	24.70	18.89
Nylon	Third	8.25	1787.80	328.25	27.10	18.14
Nylon	Fourth	9.19	2000.98	296.08	20.48	17.51
Nylon	Fifth	9.17	2845.35	422.86	20.43	16.63

Looking at the stress value of Nylon braided composite rods, it is observed from the Table 4.20 and figure 4.20 that as the diameter increases the load-bearing capacity of the Nylon braided composite rod decreases, this can be attributed to a larger diameter, the outer layers bear more load compared to the inner layers.

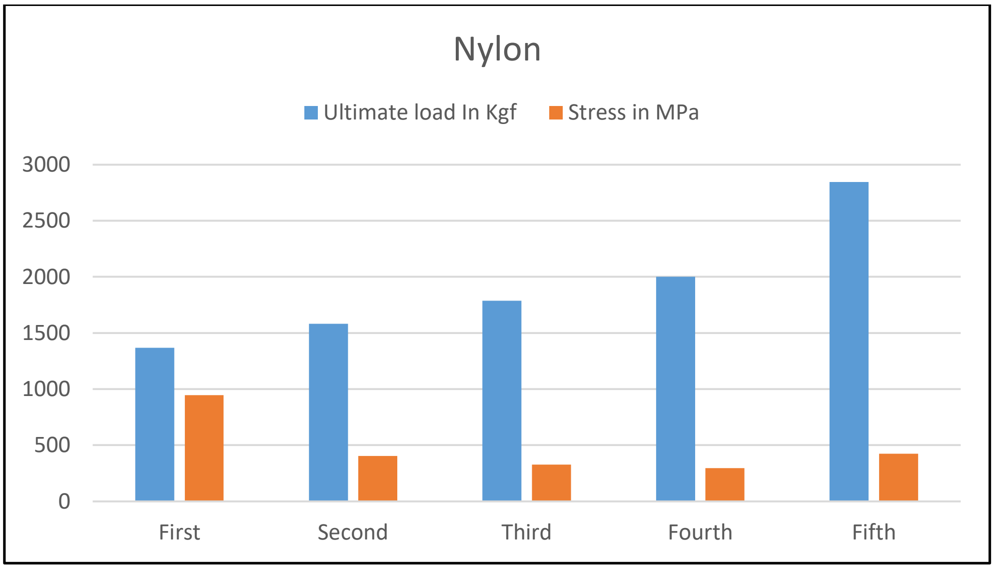

Figure 4.20 Comparison of ultimate load with stress

In braided structures, the angle at which fibers are interwoven (braiding angle) influences the mechanical properties. As the diameter increases, the braiding angle often changes, leading to less optimal fiber alignment for bearing axial loads. This uneven distribution can cause a reduction in the overall stress-bearing capacity of the rope as a composite structure. Apart from that larger diameter ropes experience higher shear forces between layers. These forces can cause slippage or deformation between layers, reducing the overall tensile strength. As seen from the Figure 4.20, the stress value decreases from the first layer to the fourth layer but a rise has been observed in the stress value for the fifth layer, this can be attributed to more concentric pressure as number of layer increases.

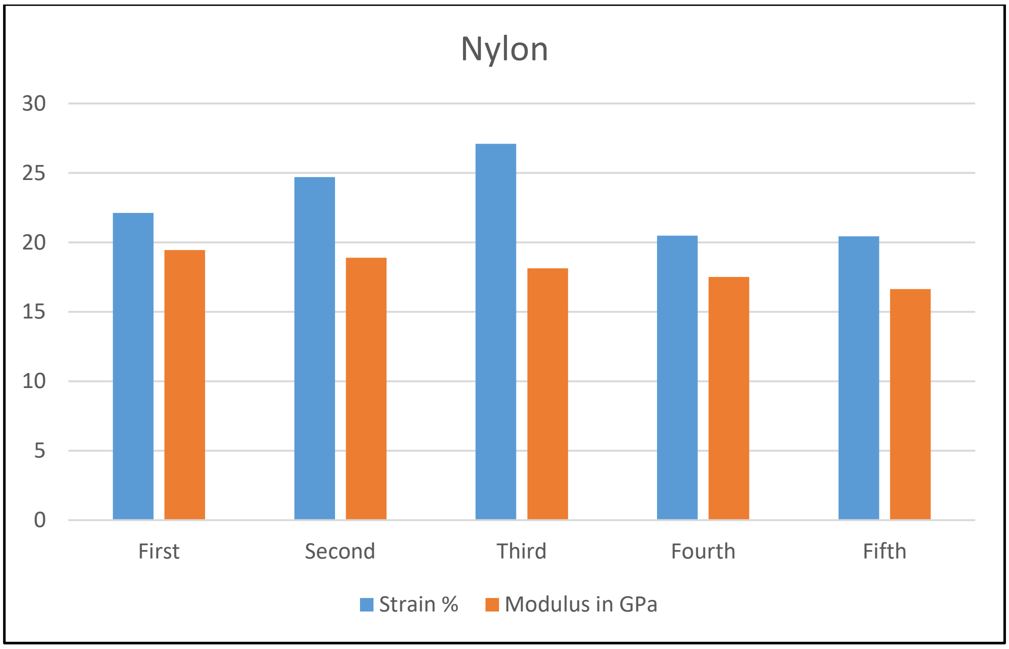

Figure 4.21 Comparison of strain % with modulus

Figure 4.21 compares nylon braided rod for its strain % with modulus. The strain percentage is also crucial in steel rebars and braided composite rods. The strain percentage becomes more important for high-altitude buildings. The percentage strain of the prepared nylon braided composite rods ranges from 16% to 19%, which is very well in the range defined by steel grade IS requirement of 10% to 23%. Apart from that modulus of the prepared rod also remains almost constant. This suggests that the material becomes stiffer and potentially more brittle with each successive layer, which could be a deliberate design choice to meet specific mechanical requirements in applications where higher load-bearing capacity and stiffness are desired.

4.5.1.3 Basalt BCR

The data presented in Table 4.21 and Figure 4.22 offers a comprehensive view of the tensile properties of Basalt braided rods across five different layers. The initial layer features a rod diameter of 4.50 mm and an ultimate load capacity of 1087.32 Kgf, which increases with an increase in rod diameter leading to a maximum strength of 2856.24 Kgf of the fifth layer with 9.10 mm rod diameter, which is evident that as diameter increases the rod strength increases.

Table 4.21 Tensile properties of basalt BCR

Material	Layer number	Rod Dia. (mm)	Ultimate load (Kgf)	Stress (MPa)	Strain (%)	Modulus (GPa)
Basalt	First	4.50	1087.32	671.01	9.16	42.09
Basalt	Second	6.35	1410.74	437.22	11.22	40.63
Basalt	Third	8.00	1928.23	376.51	14.89	39.01
Basalt	Fourth	8.54	2209.05	378.52	15.98	37.45
Basalt	Fifth	9.10	2856.24	431.03	16.02	36.40

Looking at the stress value of Basalt braided composite rods, it is observed from the Table 4.21 and Figure 4.23 that as the diameter increases the load-bearing capacity of the Basalt braided composite rod decreases as the effective tensile force that each fiber can carry is reduced due to less optimal alignment and increased structural imperfections as diameter increases. In braided structures, the angle at which fibers are interwoven (braiding angle) influences the mechanical properties. This uneven distribution can cause a reduction in the overall stress-bearing capacity of the rope as a composite structure. Apart from that larger diameter ropes experience higher shear forces between layers. These forces can cause slippage or deformation between layers, reducing the overall tensile strength. As seen from the Figure 4.22, the stress value decreases from the first layer to the fourth layer but a rise has been observed in the stress value for the fifth layer, this can be attributed to more concentric pressure as number of layer increases.

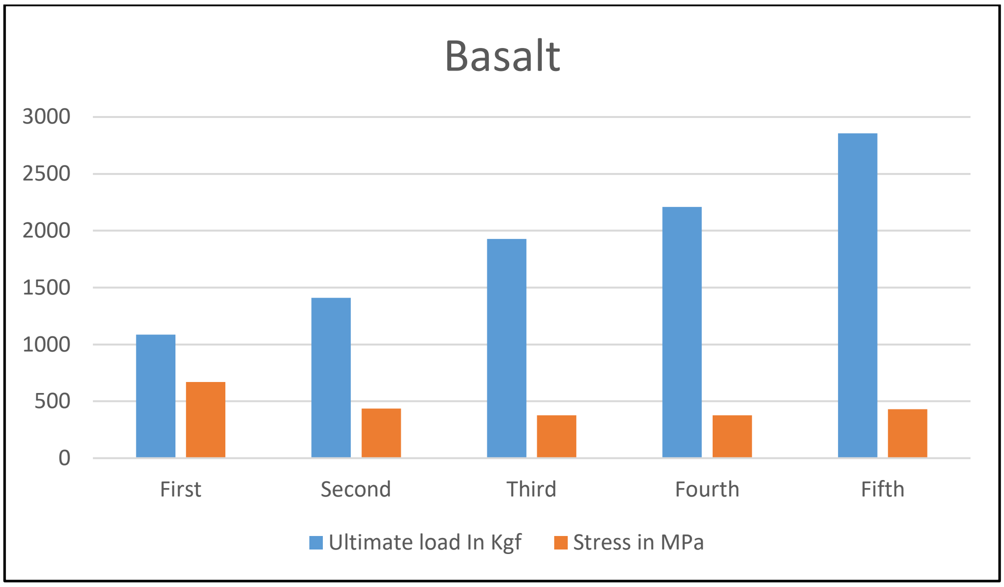

Figure 4.22 Comparison of ultimate load with stress

The strain percentage is also crucial in steel rebars and braided composite rods. The strain percentage becomes more important for high-altitude buildings. Figure 4.23 compares basalt braided rod for its tensile properties, i.e. strain % with modulus. The percentage strain of the prepared Basalt braided composite rods ranges from 9% to 16%, which is very well in the range defined by steel grade IS requirement of 10% to 23%. The data suggests that as the rod diameter increases, the material can withstand greater loads while exhibiting more significant deformation before failure. This balance of properties could be beneficial in scenarios where Basalt rods are subjected to dynamic loads or need to absorb energy without failing.

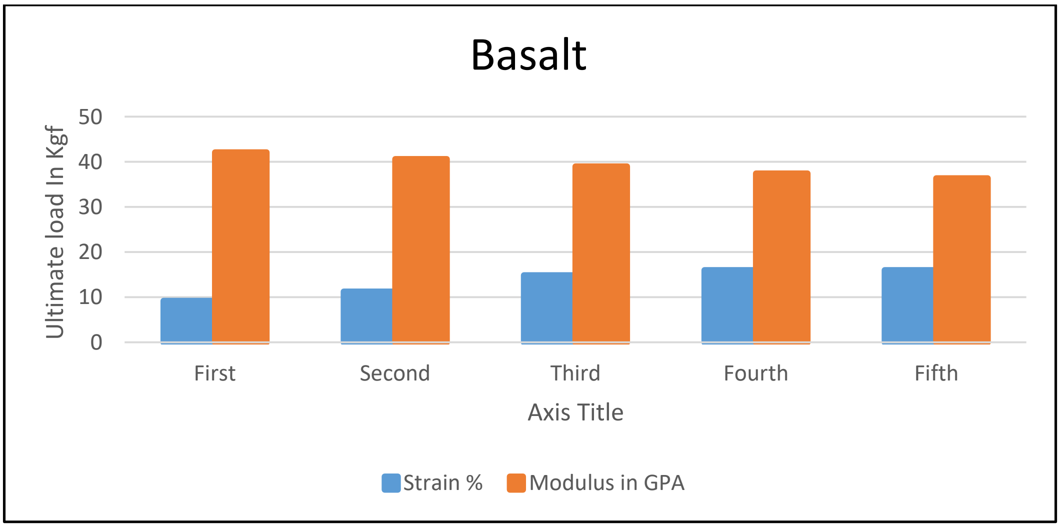

Figure 4.23 Comparison of strain % with modulus

4.5.1.4 PP + Basalt

The data presented in Table 4.22 and Figure 4.24 offers a comprehensive view of the tensile properties of PP + Basalt braided rods across five different layers. The initial layer features a rod diameter of 4.00 mm and an ultimate load capacity of 960.04 Kgf, which increases with an increase in rod diameter leading to a maximum strength of 1751.89 Kgf of the fifth layer with 8.03 mm rod diameter, which is evident that as diameter increases the rod strength increases.

Table 4.22 Tensile properties pp + basalt [35:65] BCR

Material	Layer number	Rod Dia. (mm)	Ultimate load (Kgf)	Stress (MPa)	Strain (%)	Modulus (GPa)
PP + Basalt	First	4.00	960.04	749.84	14.10	34.65
PP + Basalt	Second	5.10	989.22	475.28	11.94	33.26
PP + Basalt	Third	6.70	1230.84	342.65	14.06	32.11
PP + Basalt	Fourth	7.46	1468.90	329.85	18.83	31.21
PP + Basalt	Fifth	8.03	1751.89	339.53	19.65	29.96

Looking at the stress value of PP + Basalt braided composite rods, it is observed from the Table 4.22 and Figure 4.20 that as the diameter increases the load-bearing capacity of the PP + Basalt braided composite rod decreases, this can be attributed to a larger diameter, the outer layers bear more load compared to the inner layers. This uneven distribution can cause a reduction in the overall stress-bearing capacity of the rope as a composite structure.

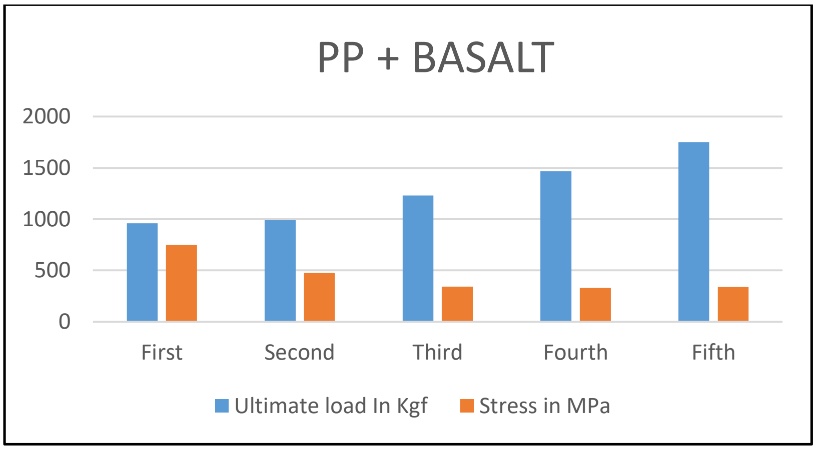

Figure 4.24 Comparison of ultimate load with stress

Apart from that larger diameter ropes experience higher shear forces between layers. These forces can cause slippage or deformation between layers, reducing the overall tensile strength. As seen from the Figure 4.20, the stress value decreases from the first layer to the fourth layer but a sudden rise has been observed in the stress value for the fifth layer, this can be attributed to more concentric pressure as number of layer increases.

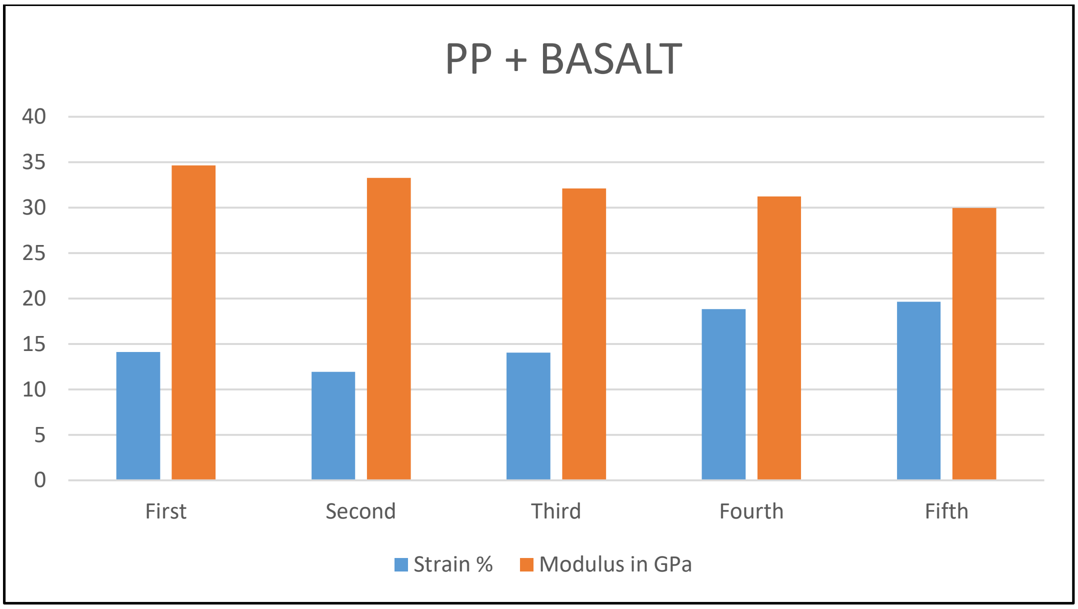

Figure 4.25 Comparison of strain % with modulus

The strain percentage is also crucial in steel rebars and braided composite rods. The strain percentage becomes more important for high-altitude buildings. As shown in Figure 4.25, the percentage strain of the prepared PP + Basalt braided composite rods ranges from 14% to 20%, which is very well in the range defined by steel grade IS requirement of 10% to 23%. Apart from that modulus of the prepared rod also remains almost constant. The data suggests that as the rod diameter increases, the material can withstand greater loads while exhibiting more significant deformation before failure. This balance of properties could be beneficial in scenarios where Basalt rods are subjected to dynamic loads or need to absorb energy without failing.

4.5.1.5 Nylon + Basalt

The data presented in Table 4.23 and Figure 4.26 offers a comprehensive view of the tensile properties of Nylon + Basalt braided rods across five different layers. The initial layer features a rod diameter of 4.00 mm and an ultimate load capacity of 1196.35 Kgf, which increases with an increase in rod diameter leading maximum strength of 2869.29 Kgf of the fifth layer with 8.75 mm rod diameter, which is evident that as diameter increases the rod strength increases.

Table 4.23 Tensile properties nylon + basalt braided [50:50] BCR

Material	Layer number	Rod Dia. (mm)	Ultimate load (Kgf)	Stress (MPa)	Strain (%)	Modulus (GPa)
Nylon + Basalt	First	4.00	1196.35	934.41	11.56	30.95
Nylon + Basalt	Second	5.80	1288.75	478.75	12.52	29.88
Nylon + Basalt	Third	7.00	1838.89	468.99	14.42	29.04
Nylon + Basalt	Fourth	7.99	2119.73	414.94	16.07	27.88
Nylon + Basalt	Fifth	8.75	2869.29	468.34	18.96	26.76

Looking at the stress value of Nylon + Basalt braided composite rods, it is observed from the Table 4.23 and Figure 4.26 that as the diameter increases the load-bearing capacity of the Nylon + Basalt braided composite rod decreases, this can be attributed to a larger diameter, the outer layers bear more load compared to the inner layers.

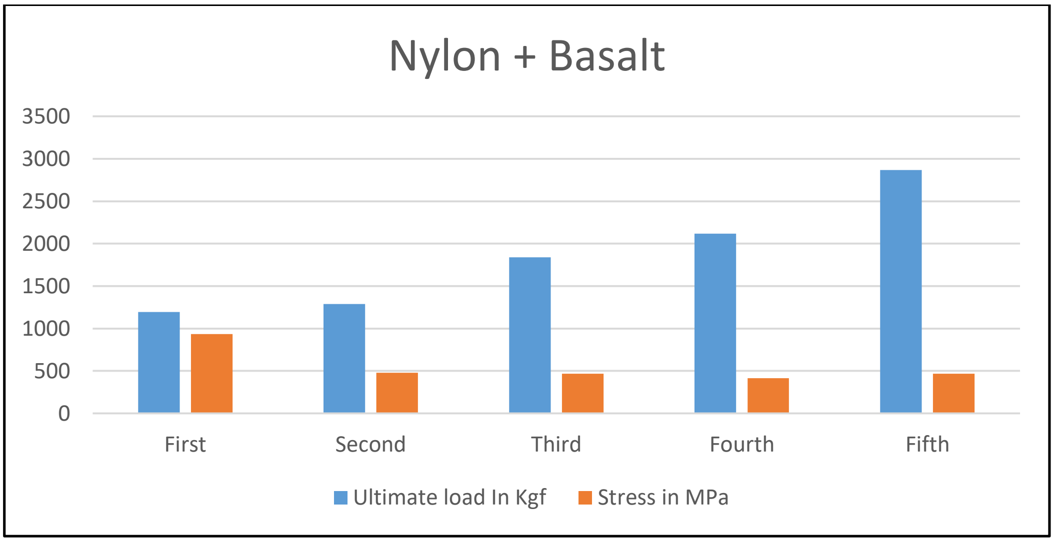

Figure 4.26 Comparison of ultimate load with stress

In braided structures, the angle at which fibers are interwoven (braiding angle) influences the mechanical properties. As the diameter increases, the braiding angle often changes, leading to less optimal fiber alignment for bearing axial loads. This uneven distribution can cause a reduction in the overall stress-bearing capacity of the rope as a composite structure. Apart from that larger diameter ropes experience higher shear forces between layers. These forces can cause slippage or deformation between layers, reducing the overall tensile strength. As seen from Figure 4.26, the stress value decreases from the first layer to the fourth layer but a sudden rise has been observed in the stress value for the fifth layer, this can be attributed to more concentric pressure as the number of layers increases.

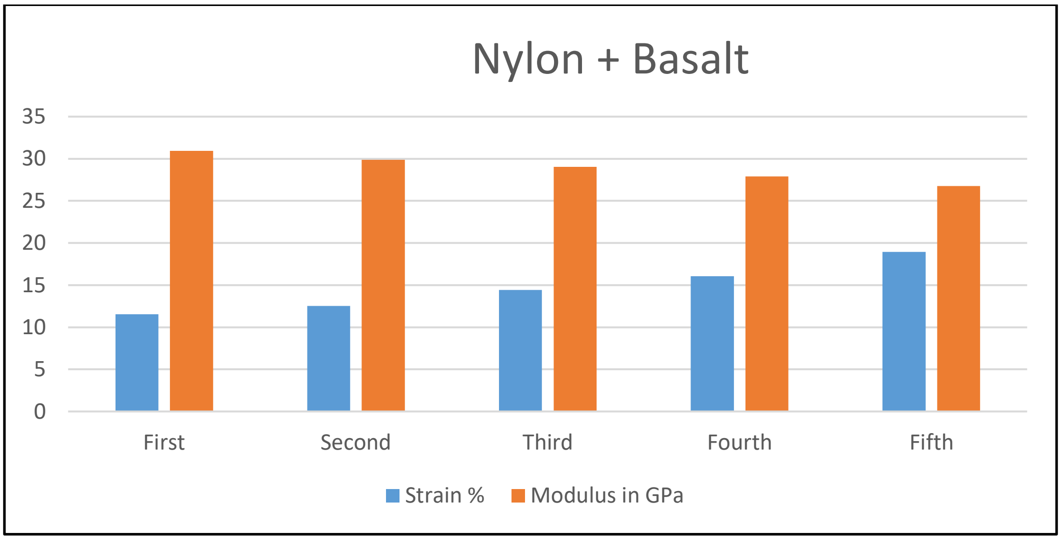

Figure 4.27 Comparison of strain % with modulus

The strain percentage is also crucial in steel rebars and braided composite rods. The strain percentage becomes more important for high-altitude buildings. Figure 4.27 the percentage strain of the prepared Nylon + Basalt braided composite rods ranges from 11% to 19%, which is very well in the range defined by steel grade IS requirement of 10% to 23%. Apart from that modulus of the prepared rod also remains almost constant. This suggests that the material becomes stiffer and potentially more brittle with each successive layer, which could be a deliberate design choice to meet specific mechanical requirements in applications where higher load-bearing capacity and stiffness are desired.

4.5.2 Comparison within Layer

In this section, we have tried to compare the mechanical properties of prepared braided composite rods made from different raw materials, layer wise. The objective of this comparison is to made a decision on which type of material to be used as per requirement.

4.5.2.1 First layer

The tensile test results for the first layer of braided rods made from different materials reveal significant variations in performance (Figure 4.24 & Table 4.24). Polypropylene (PP), with a rod diameter of 5.00 mm, exhibited an ultimate load of 786.12 Kgf and a stress of 392.96 MPa. Notably, it had the highest strain percentage at 31.09%, indicating a higher degree of elasticity, but a lower modulus of 21.74 GPa, suggesting less stiffness compared to other materials.

Table 4.24 First layer braided rod tensile properties comparison

Material	Layer number	Rod Dia. (mm)	Ultimate load (Kgf)	Stress (MPa)	Strain (%)	Modulus (GPa)
PP	First	5.00	786.12	392.96	31.09	21.74
Basalt	First	4.50	1087.32	671.01	9.16	42.09
PP + Basalt [35:65]	First	4.00	960.04	749.84	14.10	34.65
Nylon + Basalt [50:50]	First	4.00	1196.35	934.41	11.56	30.95
Nylon	First	4.25	1367.10	945.85	22.12	19.44

Nylon, with a smaller diameter of 4.25 mm, showed a much higher ultimate load capacity of 1367.10 Kgf and stress of 945.85 MPa, reflecting its superior strength. However, its strain percentage was lower at 22.12%, and the modulus was 19.44 GPa, indicating that while it is stronger, it is also less stiff than PP. Basalt rods, measuring 4.50 mm in diameter, presented an ultimate load of 1087.32 Kgf and a stress of 671.01 MPa. Its strain percentage was the lowest at 9.16%, which correlates with the highest modulus of 42.09 GPa, signifying that basalt is the stiffest material among those tested.

The composite materials, PP + Basalt (35:65) and Nylon + Basalt (50:50), both with diameters of 4.00 mm, demonstrated interesting properties. The PP and Basalt composite bore an ultimate load of 960.04 Kgf and a stress of 749.84 MPa, with a strain percentage of 14.10% and a modulus of 34.65 GPa. This suggests a balanced compromise between elasticity and stiffness. The Nylon and Basalt composite carried an ultimate load of 1196.35 Kgf and a stress of 934.41 MPa, with a strain percentage of 11.56% and a modulus of 30.95 GPa, indicating a material that is both strong and relatively stiff.

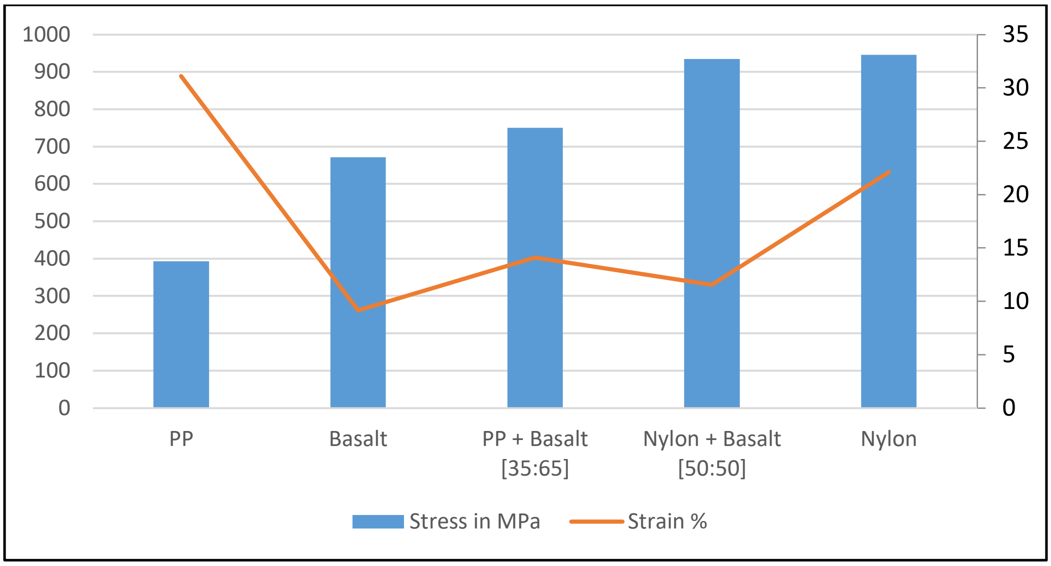

Figure 4.28 First layer braided rod tensile properties comparison

This change in load bearing capacity of braided composite rod of first layer is due to the change in the reinforcement material. Here, different variety of yarn which differ in their tensile properties are used as reinforcement material, which is responsible for change in load bearing capacity. Apart from that, variation in fibre volume fraction also affects the strength of braided ropes.

It is also observed from Figure 4.28, that strain behavior of braided composite rod is completely inverse than its stress value. In the case of less stress the extension percentage increases and vice-versa.

4.5.2.2 Second layer

The tensile test results for the second layer of braided rods shown in Table 4.25 & Figure 4.29, shows a diverse range of mechanical properties across different materials. For Polypropylene (PP), the rod diameter increased to 5.50 mm from the first layer, and correspondingly, the ultimate load also increased to 994.22 Kgf. The stress experienced by PP is 410.73 MPa, and the strain percentage decreased to 23.21%, indicating less elasticity than the first layer. The modulus of elasticity slightly decreased to 20.65 GPa, suggesting a minor reduction in stiffness. Nylon rods, with a significant increase in diameter to 7.00 mm, showed an increased ultimate load of 1581.44 Kgf. Interestingly, the stress decreased to 403.33 MPa, and the strain percentage increased to 24.70%, indicating that the second layer of Nylon is less strong but more elastic than the first layer.

Table 4.25 Second layer braided rod tensile properties comparison

Material	Layer number	Rod Dia. (mm)	Ultimate load (Kgf)	Stress (MPa)	Strain (%)	Modulus (GPa)
Nylon	Second	7.00	1581.44	403.33	24.70	18.89
PP	Second	5.50	994.22	410.73	23.21	20.65
Basalt	Second	6.35	1410.74	437.22	11.22	40.63
PP + Basalt [35:65]	Second	5.10	989.22	475.28	11.94	33.26
Nylon + Basalt [50:50]	Second	5.80	1288.75	478.75	12.52	29.88

The modulus of elasticity also decreased to 18.89 GPa, pointing to a decrease in stiffness. For Basalt, the diameter increased to 6.35 mm, and the ultimate load reached 1410.74 Kgf. The stress for Basalt increased to 437.22 MPa, and the strain percentage slightly increased to 11.22%, while the modulus of elasticity decreased to 40.63 GPa. These changes suggest that the second layer of Basalt is stronger but slightly less stiff than the first layer.

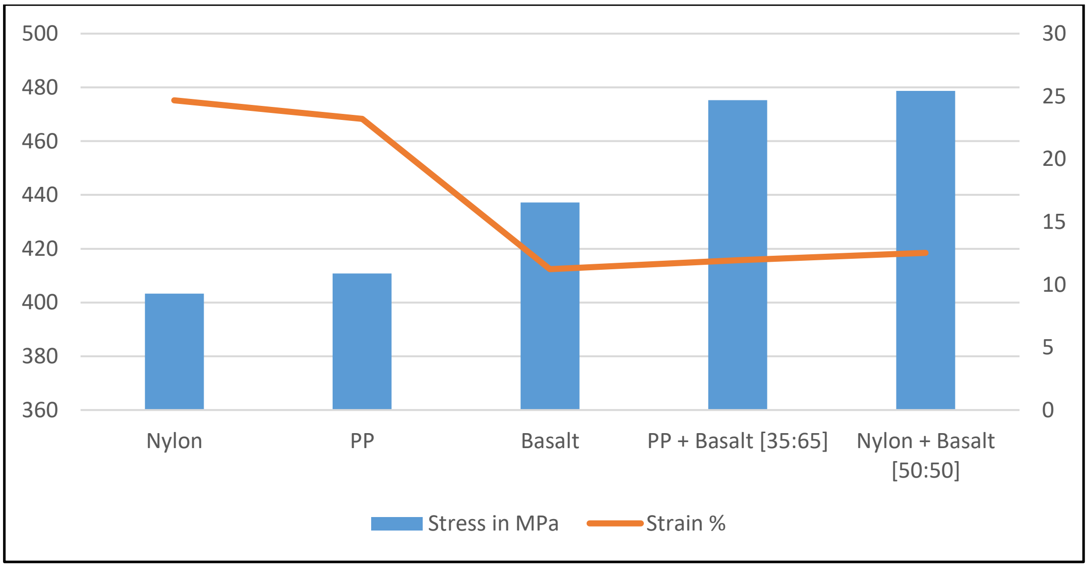

Figure 4.29 Second layer braided rod tensile properties comparison

The composite material PP + Basalt (35:65) saw a slight increase in rod diameter to 5.10 mm and a corresponding increase in ultimate load to 989.22 Kgf. The stress significantly increased to 475.28 MPa, and the strain percentage rose to 11.94%, with a decrease in the modulus of elasticity to 33.26 GPa. This indicates that the second layer of this composite is stronger and more elastic but less stiff than the first layer. Lastly, the Nylon + Basalt (50:50) composite, with a diameter of 5.80 mm, showed an ultimate load of 1288.75 Kgf. The stress slightly increased to 478.75 MPa, and the strain percentage rose to 12.52%. The modulus of elasticity decreased to 29.88 GPa, suggesting that the second layer is stronger, more elastic, and less stiff than the first layer.

This change in load bearing capacity of braided composite rod of second layer is due to the change in the reinforcement material. Here, different variety of yarn which differ in their tensile properties are used as reinforcement material, which is responsible for change in load bearing capacity. Apart from that, variation in fibre volume fraction also affects the strength of braided ropes.

It is also observed from Figure 4.25, that strain behavior of braided composite rod is completely inverse than its stress value. In the case of less stress the extension percentage increases and vice-versa.

4.5.2.3 Third layer

The data from Table 4.26 & Figure 4.30, reflects the tensile properties of the third layer of braided rods, revealing how different materials respond under tension. The polypropylene (PP) rod diameter is now 7.00 mm, and the ultimate load it can bear is 1186.14 Kgf. The stress experienced by PP is 302.51 MPa, with a strain percentage of 22.03%. The modulus of elasticity is 19.83 GPa, indicating that the material is quite resilient, maintaining a high strain percentage while the stress has decreased compared to the second layer. Nylon with a larger diameter of 8.25 mm, the ultimate load for Nylon increases to 1787.80 Kgf. The stress is 328.25 MPa, and the strain percentage is 27.10%, the highest among the materials, suggesting Nylon is the most elastic. The modulus of elasticity is 18.14 GPa, showing a decrease in stiffness, which correlates with the increased elasticity. Basalt rod diameter is 8.00 mm, and it has an ultimate load of 1928.23 Kgf, the highest among the materials. The stress is 376.51 MPa, and the strain percentage is 14.89%. The modulus of elasticity is a high 39.01 GPa, indicating Basalt's superior stiffness and strength.

Table 4.26 Third layer braided rod tensile properties comparison

Material	Layer number	Rod Dia. (mm)	Ultimate load (Kgf)	Stress (MPa)	Strain (%)	Modulus (GPa)
PP	Third	7.00	1186.14	302.51	22.03	19.83
Nylon	Third	8.25	1787.80	328.25	27.10	18.14
PP + Basalt [35:65]	Third	6.70	1230.84	342.65	14.06	32.11
Basalt	Third	8.00	1928.23	376.51	14.89	39.01
Nylon + Basalt [50:50]	Third	7.00	1838.89	468.99	14.42	29.04

PP + Basalt (35:65) composite material has a rod diameter of 6.70 mm and an ultimate load of 1230.84 Kgf. The stress is 342.65 MPa, and the strain percentage is 14.06%. The modulus of elasticity is 32.11 GPa, which suggests that the composite has good strength and stiffness, benefiting from the properties of both PP and Basalt. Nylon + Basalt (50:50) with a rod diameter of 7.00 mm, this composite bears an ultimate load of 1838.89 Kgf. The stress is 468.99 MPa, the highest recorded stress, and the strain percentage is 14.42%. The modulus of elasticity is 29.04 GPa, indicating that this composite is strong and has a reasonable level of stiffness, likely due to the balanced contribution of Nylon and Basalt.

This change in load bearing capacity of braided composite rod of third layer is due to the change in the reinforcement material. Here, different variety of yarn which differ in their tensile properties are used as reinforcement material, which is responsible for change in load bearing capacity. Apart from that, variation in fibre volume fraction also affects the strength of braided ropes.

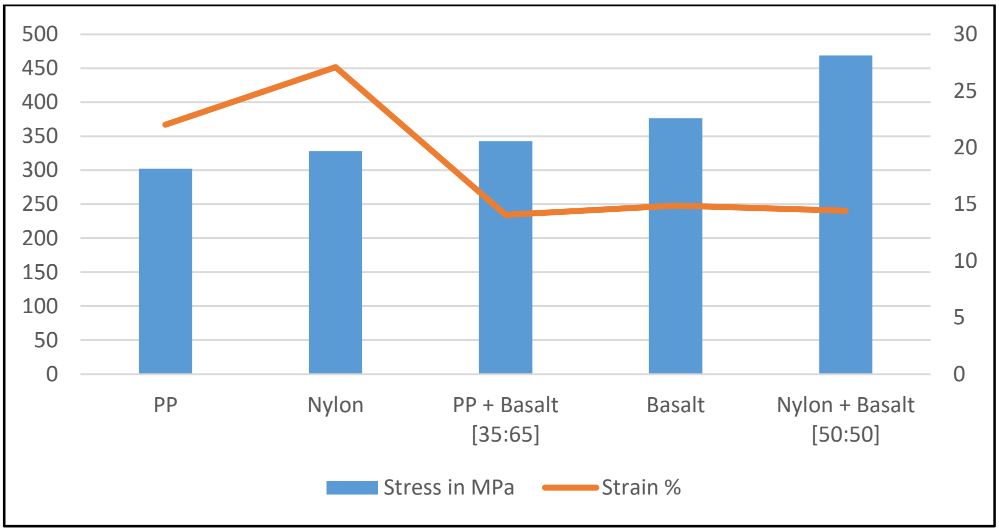

Figure 4.30 Third layer braided rod tensile properties comparison

It is also observed from Figure 4.30, that strain behavior of braided composite rod is completely inverse than its stress value. In the case of less stress the extension percentage increases and vice-versa.

4.5.2.4 Fourth layer

The data presented in Table 4.27 & Figure 4.31 provides insights into the tensile properties of various materials in the fourth layer of braided rods. Here's a detailed analysis Polypropylene (PP) rod diameter has slightly increased to 7.38 mm compared to the third layer. It can withstand an ultimate load of 1347.87 Kgf, which is higher than the previous layer. The stress it experiences is 309.27 MPa, and the strain percentage is 21.46%, indicating a slight decrease in elasticity with a modulus of 19.14 GPa, suggesting a minor reduction in resilience. The rod diameter for Nylon is now 9.19 mm, and it can bear an ultimate load of 2000.98 Kgf. The stress is 296.08 MPa, which is lower than the third layer, and the strain percentage is 20.48%, showing a slight decrease in elasticity. The modulus of elasticity is 17.51 GPa, indicating a decrease in stiffness, which aligns with the increased diameter and load-bearing capacity.

Table 4.27 Fourth layer braided rod tensile properties comparison

Material	**Layer number**	**Rod Dia. (mm)**	**Ultimate load (Kgf)**	**Stress (MPa)**	**Strain (%)**	**Modulus (GPa)**
Nylon	Fourth	9.19	2000.98	296.08	20.48	17.51
PP	Fourth	7.38	1347.87	309.27	21.46	19.14
PP + Basalt [35:65]	Fourth	7.46	1468.90	329.85	18.83	31.21
Basalt	Fourth	8.54	2209.05	378.52	15.98	37.45
Nylon + Basalt [50:50]	Fourth	7.99	2119.73	414.94	16.07	27.88

With a rod diameter of 8.54 mm, Basalt can handle an ultimate load of 2209.05 Kgf, the highest among the materials. The stress is 378.52 MPa, and the strain percentage is 15.98%. The modulus of elasticity is 37.45 GPa, which is slightly lower than the third layer, yet it still reflects Basalt’s significant stiffness and strength.

PP + Basalt (35:65) composite has a rod diameter of 7.46 mm and an ultimate load of 1468.90 Kgf. The stress is 329.85 MPa, and the strain percentage is 18.83%. The modulus of elasticity is 31.21 GPa, showing that the composite maintains good stiffness and strength, with a slight increase in stress and a decrease in strain percentage compared to the third layer. Nylon + Basalt (50:50) rod diameter for this composite is 7.99 mm, and it can withstand an ultimate load of 2119.73 Kgf. The stress is 414.94 MPa, the highest among the materials, and the strain percentage is 16.07%. The modulus of elasticity is 27.88 GPa, indicating that this composite has a high level of strength and a moderate level of stiffness, likely due to the balanced contribution of Nylon and Basalt.

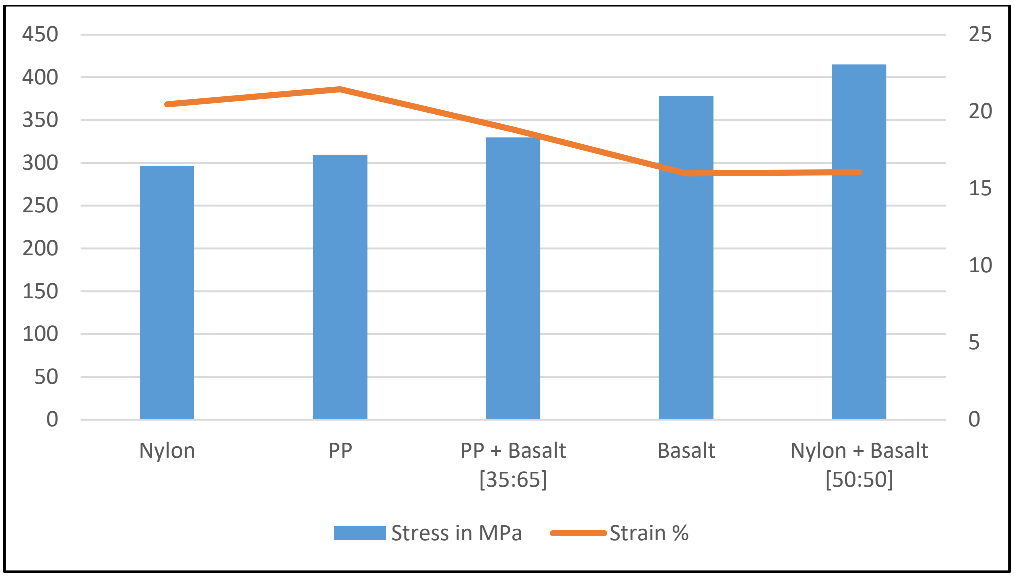

Figure 4.31 Fourth layer braided rod tensile properties comparison

This change in load bearing capacity of braided composite rod of fourth layer is due to the change in the reinforcement material. Here, different variety of yarn which differ in their tensile properties are used as reinforcement material, which is responsible for change in load bearing capacity. Apart from that, variation in fibre volume fraction also affects the strength of braided ropes.

It is also observed from Figure 4.31, that strain behavior of braided composite rod is completely inverse than its stress value. In the case of less stress the extension percentage increases and vice-versa.

4.5.2.5 Fifth layer

The data in Table 4.28 & figure 4.32 reflects the tensile properties of various materials in the fifth layer of braided rods, indicating a progression in mechanical characteristics from the fourth layer. Polypropylene (PP) Exhibits an increase in rod diameter to 7.84 mm and a significant rise in ultimate load capacity to 1889.88 Kgf. The stress experienced by PP is 384.24 MPa, with a strain percentage of 21.71%, suggesting enhanced strength while maintaining a high level of elasticity. The modulus of elasticity is 18.60 GPa, indicating a slight improvement in material stiffness. Nylon With a rod diameter of 9.17 mm, shows a remarkable increase in ultimate load to 2845.35 Kgf. The stress it can endure is 422.86 MPa, and the strain percentage is 20.43%, demonstrating a balance between strength and flexibility. The modulus of elasticity is 16.63 GPa, slightly lower than the fourth layer, which may be attributed to the material's increased load-bearing capacity. The rod diameter slightly decreases to 9.10 mm, yet Basalt's ultimate load capacity is the highest at 2856.24 Kgf. It endures a stress of 431.03 MPa and has a strain percentage of 16.02%. The modulus of elasticity is 36.40 GPa, reflecting Basalt's superior stiffness and strength among the materials tested.

Table 4.28 Fifth layer braided rod tensile properties comparison

Material	Layer number	Rod Dia. (mm)	Ultimate load (kgf)	Stress (MPa)	Strain (%)	Modulus (GPa)
PP + Basalt [35:65]	Fifth	8.03	1751.89	339.53	19.65	29.96
PP	Fifth	7.84	1889.88	384.24	21.71	18.60
Nylon	Fifth	9.17	2845.35	422.86	20.43	16.63
Basalt	Fifth	9.10	2856.24	431.03	16.02	36.40
Nylon + Basalt [50:50]	Fifth	8.75	2869.29	468.34	18.96	26.76

PP + Basalt (35:65) composite's rod diameter is 8.03 mm, with an ultimate load of 1751.89 Kgf. It experiences a stress of 339.53 MPa and a strain percentage of 19.65%. The modulus of elasticity is 29.96 GPa, indicating that the composite benefits from the combined properties of PP and Basalt, resulting in a material that is strong yet less stiff than pure Basalt. Nylon + Basalt (50:50) rod diameter for this composite is 8.75 mm, and it can withstand an ultimate load of 2869.29 Kgf, the highest among the composites. It experiences a stress of 468.34 MPa and a strain percentage of 18.96%. The modulus of elasticity is 26.76 GPa, showcasing a composite that is exceptionally strong and moderately stiff, likely due to the synergistic effect of Nylon and Basalt.

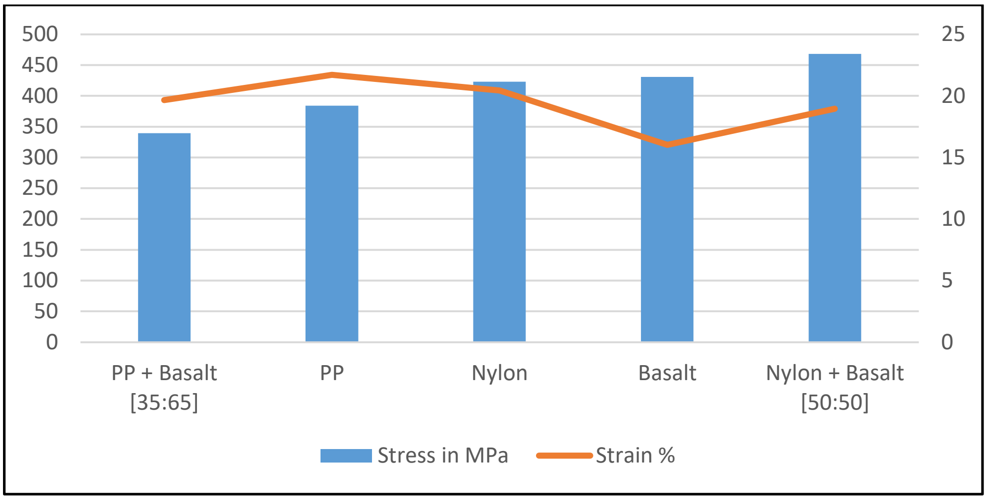

Figure 4.32 Fifth layer braided rod tensile properties comparison

This change in load bearing capacity of braided composite rod of fifth layer is due to the change in the reinforcement material. Here, different variety of yarn which differ in their tensile properties are used as reinforcement material, which is responsible for change in load bearing capacity. Apart from that, variation in fibre volume fraction also affects the strength of braided ropes.

It is also observed from Figure 4.32, that strain behavior of braided composite rod is completely inverse than its stress value. In the case of less stress the extension percentage increases and vice-versa.

4.6 Bond Strength of BCR by Pull Out

4.6.1 Polypropylene BCR

The Table 4.29 & Figure 4.33 presents a comparison of polypropylene braided rebar's (FRP bars) with steel rebar's in terms of their performance in a pullout test within a concrete block, which is a measure of bond strength. The polypropylene rebar's evaluated at two different layers, layer 4 and layer 5, with rod diameters of 7.38 mm and 7.84 mm respectively. The ultimate load capacity of the polypropylene rebar's is significantly higher than that of the steel rebar, with the fourth layer polypropylene rebar handling 441.30 kN and the fifth layer handling 506.11 kN, compared to the steel rebar's 357.16 kN. Similarly, the ultimate stress for polypropylene rebar's is greater, with the fourth layer at 176.79 MPa and the fifth layer at 198.77 MPa, versus the steel rebar's 141.36 MPa.

Table 4.29 Comparison of BCR and steel rebar for bond strength

Material	Layer	Rod Diameter (mm)	Ultimate load (kN)	Ultimate Stress (MPa)
Polypropylene	Fourth	7.38	441.3	176.79
Polypropylene	Fifth	7.84	506.11	198.77
Steel rebars	--	8.35	357.16	141.36

The superior performance of the Polypropylene BCR bars suggests that they provide better bonding and load transfer characteristics within the concrete block compared to steel rebar. This makes Polypropylene FRP bars a highly effective reinforcement material, potentially offering significant advantages in applications requiring high pullout resistance and stress endurance in concrete structures. The noticeable difference in performance between the 4-layer and 5-layer Polypropylene FRP bars also highlights the importance of optimizing the layering to achieve maximum efficacy.

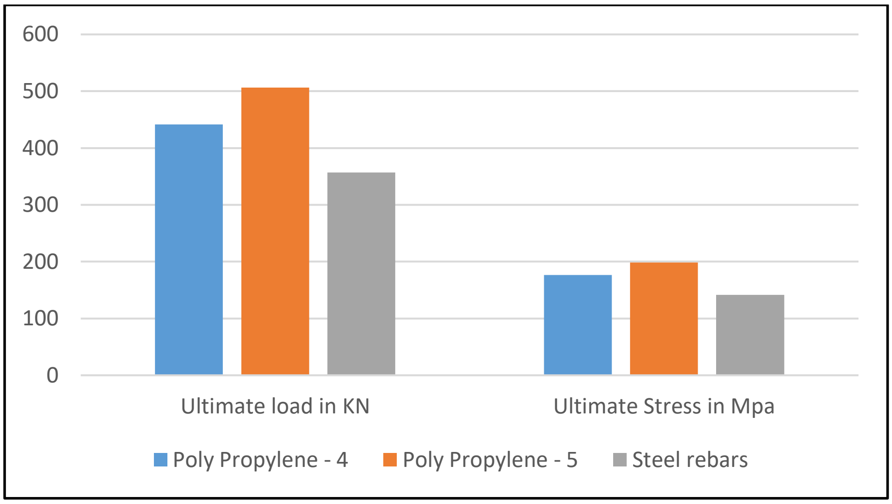

Figure 4.33 Comparison of BCR and steel rebar for bond strength

4.6.2 Nylon BCR

Table 4.30 & Figure 4.34 present a comparison between Nylon braided rebars (BCR bars) and traditional steel rebars in terms of their performance in a concrete block pullout test, which evaluates bond strength. The Nylon rebars are tested at two different layers, layer 4 and layer 5, with rod diameters of 9.19 mm and 9.17 mm respectively.

Table 4.30 Comparison of BCR and steel rebar for bond strength

Material	Layer	Rod Diameter (mm)	Ultimate load (kN)	Ultimate Stress (MPa)
Nylon	Fourth	9.19	227.06	99.68
Nylon	Fifth	9.17	328.73	143.68
Steel rebars	--	8.35	357.16	141.36

The ultimate load capacity of the Nylon rebars is lower than that of the steel rebar, with the fourth layer Nylon rebar handling 227.06 kN and the fifth layer handling 328.73 kN, compared to the steel rebar's 357.16 kN. However, the ultimate stress for Nylon rebars is comparable to that of the steel rebar, with the fourth layer at 99.68 MPa and the fifth layer at 143.68 MPa, versus the steel rebar's 141.36 MPa. The decrease in load-bearing capacity of Nylon rebars could be due to slippage between the layers and slippage between prepared rod and concrete material. As the prepared rods are from Nylon material changes of slippage is more due to surface characteristics of Nylon material. Better results with fifth layers may be due to more surface area available for bonding.

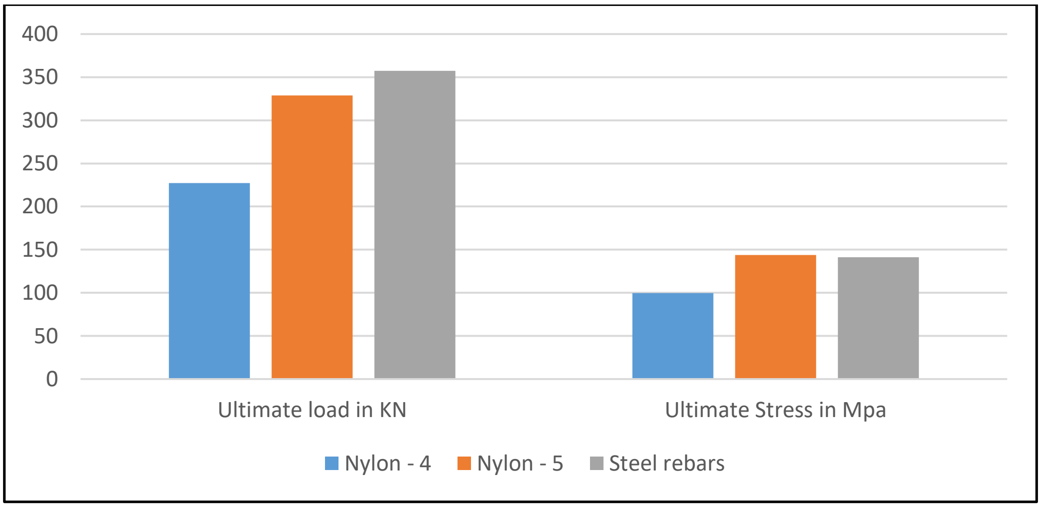

Figure 4.34 Comparison of BCR and steel rebar for bond strength

4.6.3 Basalt BCR

Table 4.31 & Figure 4.35 presents a comparison of the performance of basalt braided rebars and traditional steel rebars in terms of concrete bond strength. The data indicates that basalt rebars, with layers 4 and 5, have rod diameters of 8.53 mm and 9.1 mm, respectively. The ultimate load capacity for Basalt fourth layer is 404.82 kN, which is significantly higher than the 357.16 kN for steel rebars, despite the steel having a slightly smaller diameter of 8.35 mm. Correspondingly, the ultimate stress for Basalt fourth layer is 162.15 MPa, surpassing the steel's 141.36 MPa.

Table 4.31 Comparison of BCR and steel rebar for bond strength

Material	Layer	Rod Diameter (mm)	Ultimate load (kN)	Ultimate Stress (MPa)
Basalt	Fourth	8.53	404.82	162.15
Basalt	Fifth	9.1	349.77	150.78
Steel rebars	--	8.35	357.16	141.36

The Basalt fifth layer rebar, while having a larger diameter than the steel rebar, shows a lower ultimate load of 349.77 kN and ultimate stress of 150.78 MPa. This suggests that while the basalt rebars generally outperform steel in load capacity and stress, the performance can vary with the layering of the material.

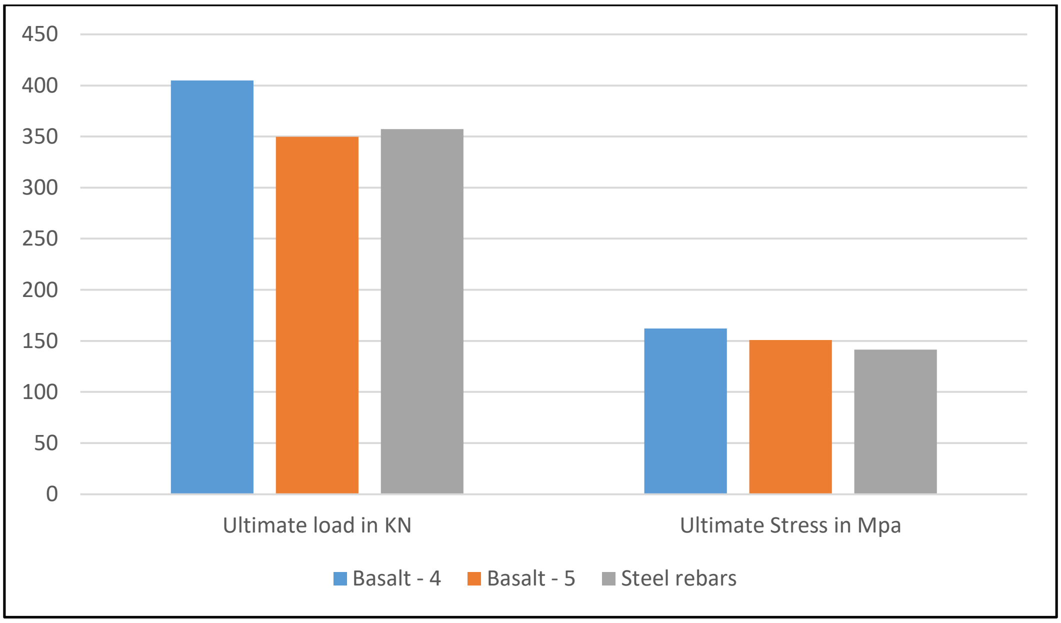

Figure 4.35 Comparison of BCR and steel rebar for bond strength

The superior performance of the fourth layer Basalt BCR suggests that they provide better bonding and load transfer characteristics within the concrete block compared to the steel rebars, making them a potentially more effective reinforcement material in concrete structures. However, the performance difference between the Basalt BCR configurations highlights the importance of optimizing the layering and diameter for maximum efficacy.

(a) Curing of samples ***(b) Sample ready for test***

(c) Sample mounting ***(d) Sample after test***

Figure 4.36 Process of pull-out test

4.6.4 PP + Basalt BCR

Table 4.32 & Figure 4.37 provide a comparative analysis of PP + Basalt braided rebars against traditional steel rebar, focusing on their bond strength within a concrete block as determined by a pullout test. The table lists two different layers for the PP + Basalt rebars, layer 4 with a rod diameter of 7.46 mm and layer 5 with a diameter of 8.03 mm. The ultimate load capacity of the PP + Basalt rebars is notably higher than that of the steel rebar, with fourth layer capable of withstanding 465.38 KN and fifth layer managing 427.22 KN, compared to the steel rebar's 357.16 KN. Furthermore, the ultimate stress for the PP + Basalt rebars is also higher, with layer 4 at 185.48 MPa and layer 5 at 167.6 MPa, versus the steel rebar's 141.36 MPa. . Overall, the PP + Basalt BCR demonstrate significant potential as an alternative to traditional steel rebars in concrete reinforcement applications.

Table 4.32 Comparison of BCR and steel rebar for bond strength

Material	Layer	Rod Diameter (mm)	Ultimate load (kN)	Ultimate Stress (MPa)
PP + Basalt	Fourth	7.46	465.38	185.48
PP + Basalt	Fifth	8.03	427.22	167.6
Steel rebars		8.35	357.16	141.37

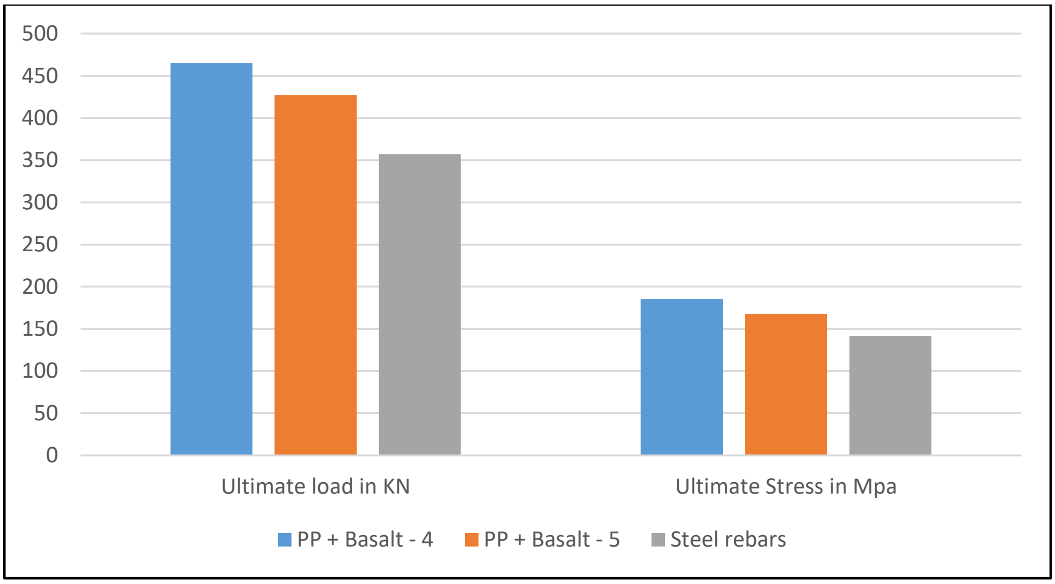

Figure 4.37 Comparison of BCR and steel rebar for bond strength

4.6.5 Nylon + basalt BCR

The data in Table 4.33 & Figure 4.38 compares the concrete bond strength of Nylon + Basalt braided rebars to traditional steel rebars. The Nylon + Basalt fourth rebars, with a diameter of 7.98 mm, exhibit an ultimate load of 378.82 kN and an ultimate stress of 148.60 MPa. These values are higher than those of steel rebars, which have a slightly larger diameter of 8.35 mm but a lower ultimate load and stress of 357.16 kN and 141.36 MPa, respectively. On the other hand, Nylon + Basalt fifth rebars, with a diameter of 8.75 mm, show a decrease in performance with an ultimate load of 313.48

kN and an ultimate stress of 128.20 MPa. This is below the performance of both Nylon + Basalt fourth layer rebars and steel rebars, indicating that the addition of nylon and the change in layering affect the bond strength.

Table 4.33 Comparison of BCR and steel rebar for bond strength

Material	Layer	Rod Diameter (mm)	Ultimate load (kN)	Ultimate Stress (MPa)
Nylon + Basalt	Fourth	7.99	378.83	148.60
Nylon + Basalt	Fifth	8.75	313.49	128.20
Steel rebars	--	8.35	357.16	141.37

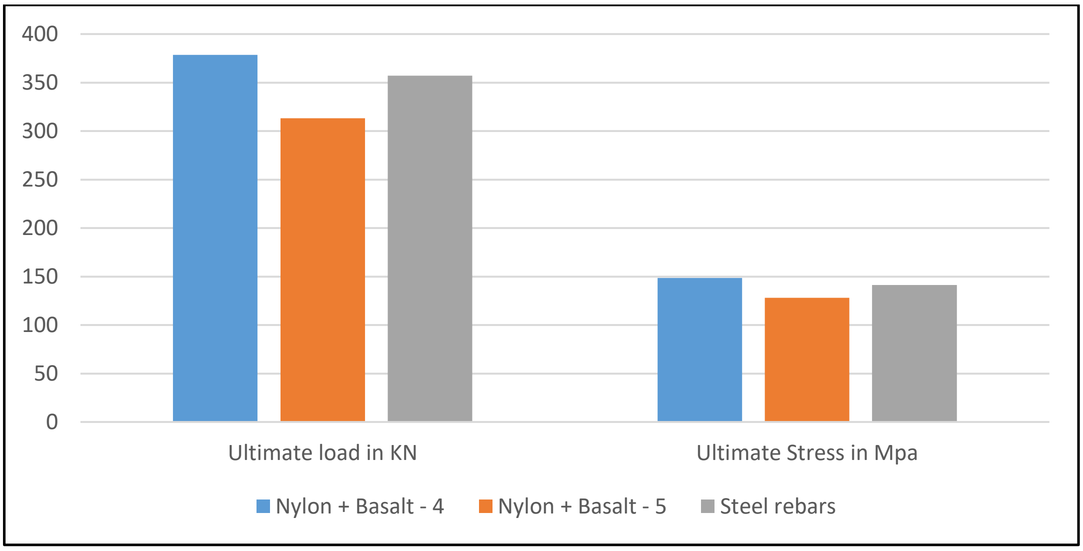

Figure 4.38 Comparison of BCR and steel rebar for bond strength

In the context of BCR pullout tests within a concrete block, these results suggest that the combination of nylon with basalt fibers can enhance the bond strength compared to traditional steel rebars, as evidenced by the Nylon + Basalt fourth layer rebars. However, the performance is dependent on the specific layering and material composition, as seen with the Nylon + Basalt fifth layer rebars. This highlights the importance of material selection and engineering design in optimizing the bond strength for BCRs in concrete applications, ensuring the structural integrity and longevity of the construction.

4.7 Flexural Strength of BCR

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. High flexural strength is essential for stress-bearing restorations in later stages for height increment of a building. The more strength a material offers, the more units a restoration can include. High flexural strength also benefits the thickness of the restoration walls. A high-strength material allows a low wall thickness. As per IS standards, flexural strength should be in the range of 3.43 to 6.20 Mpa

(a) sample testing ***(b) Sample preparation***

Figure 4.39 Flexural Strength Testing

4.7.1 Polypropylene BCR

Table 4.34 & Figure 4.40 present a comparison of the flexural strength of concrete beams reinforced with Polypropylene braided rebars against those that are unreinforced. The data indicates that the reinforced beams exhibit significantly higher flexural strength, with the Polypropylene fourth layer showing a strength of 5.48 MPa and the Polypropylene fifth layer showing 5.79 MPa. In contrast, the unreinforced beam has a flexural strength of only 3.22 MPa. This translates to an increase in flexural strength of approximately 69.91% for the Polypropylene fourth layer and 79.27% for the Polypropylene fifth layer compared to the unreinforced beam.

Table 4.34 Comparison of BCR with unreinforced beam for flexural strength

Material	Layer	Flexural Strength (MPa)
Polypropylene - 4	Fourth	5.48
Polypropylene - 5	Fifth	5.79
Unreinforced Beam	--	3.22

These results underscore the effectiveness of Braided FRP Re-bars in enhancing the flexural strength of concrete beams, which could lead to more resilient structures capable of withstanding greater stress and load as per IS standards and could be a valuable strategy in the construction industry, particularly in applications where increased flexural strength is a critical factor.

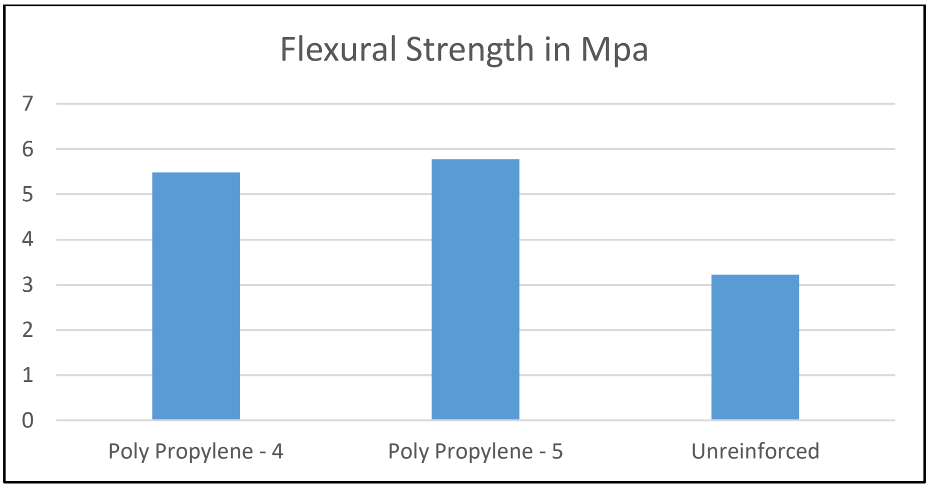

Figure 4.40 Comparison of BCR with unreinforced beam for flexural strength

4.7.2 Nylon BCR

Table 4.35 & Figure 4.41 compare the flexural strength of concrete beams reinforced with Nylon braided rebars against those that are unreinforced. The data shows that beams reinforced with Nylon fourth layer have a flexural strength of 4.60 MPa, which is an increase of 42.71% over the unreinforced beam's strength of 3.22 MPa. Similarly, beams with Nylon fifth layer reinforcement exhibit a strength of 4.76 MPa, marking an increase of 47.73% compared to the unreinforced beam.

Table 4.35 Comparison of BCR with unreinforced beam for flexural strength

Material	Layer	Flexural Strength (MPa)
Nylon	Fourth	4.60
Nylon	Fifth	4.76
Unreinforced Beam	--	3.22

These results highlight the beneficial impact of BRC on the flexural strength of concrete beams, suggesting that such reinforcement can significantly enhance the structural integrity and load-bearing capacity of concrete structures. The percentage increases in flexural strength for Nylon fourth and Nylon fifth layers demonstrate the potential for BRC to contribute to more durable and resilient construction materials as per IS standards.

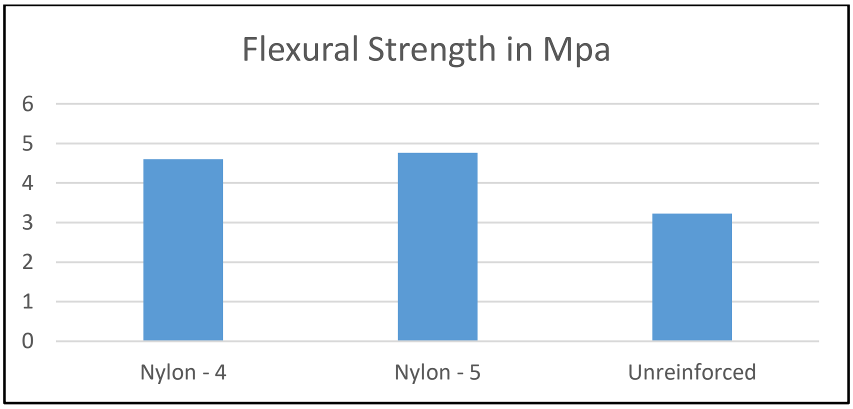

Figure 4.41 Comparison of BCR with unreinforced beam for flexural strength

4.7.3 Basalt BCR

Table 4.36 & Figure 4.42, presents a comparison of the flexural strength of concrete beams reinforced with Basalt braided rebars against those that are unreinforced.

Table 4.36 Comparison of BCR with the unreinforced beam for flexural strength

Material	Layer	Flexural Strength (MPa)
Basalt	Fourth	7.61
Basalt	Fifth	9.29
Unreinforced Beam	--	3.22

The data indicates that beams reinforced with Basalt fourth layers have a flexural strength of 7.61 MPa, which is an increase of 136.25% over the unreinforced beam's strength of 3.22 MPa. Similarly, beams with Basalt fifth layer reinforcement exhibit a strength of 9.29 MPa, marking an increase of 187.97% compared to the unreinforced beam. These findings underscore the significant enhancement in flexural strength provided by Basalt braided rebars, suggesting that such reinforcement can greatly improve the structural integrity and load-bearing capabilities of concrete structures. The substantial increases in flexural strength for Basalt fourth and Basalt fifth layers underscore the potential of BCR to contribute to the development of more robust and enduring construction materials.

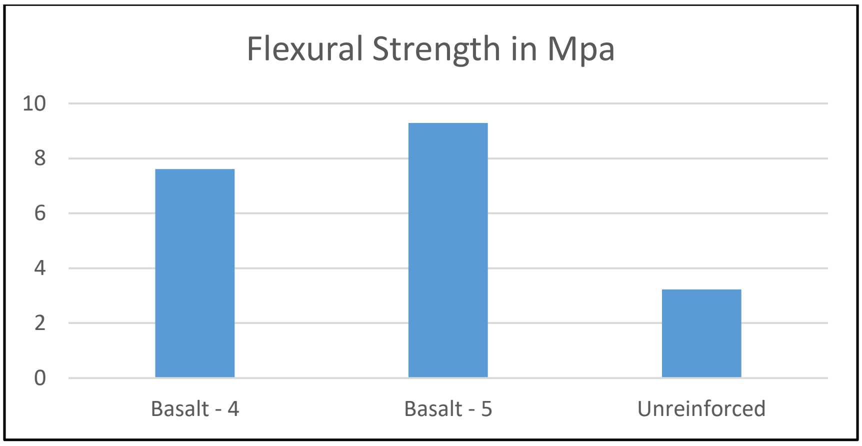

Figure 4.42 Comparison of BCR with unreinforced beam for flexural strength

4.7.4 PP + Basalt BCR

Table 4.37 & Figure 4.43 compare the flexural strength of concrete beams reinforced with PP + Basalt braided rebars against those that are unreinforced. The data shows that beams reinforced with PP + Basalt fourth layers have a flexural strength of 6.97 MPa, which is an increase of 116.25% over the unreinforced beam's strength of 3.22 MPa. Similarly, beams with PP + Basalt fifth layer reinforcement exhibit strength of 8.23 MPa, marking an increase of 155.37% compared to the unreinforced beam. These results highlight the significant improvement in flexural strength achieved through the use of PP + Basalt braided rebars, indicating that this composite material can substantially enhance the structural performance and durability of concrete beams. The marked increases in flexural strength for both PP + Basalt fourth and PP + Basalt fifth layers demonstrate the effectiveness of BCR in reinforcing concrete structures, offering a promising solution for construction that requires higher strength and longevity.

Table 4.37 Comparison of BCR with unreinforced beam for flexural strength

Material	Layer	Flexural Strength (MPa)
PP + Basalt	Fourth	6.97
PP + Basalt	Fifth	8.23
Unreinforced Beam	--	3.22

This data illustrates that the integration of PP and basalt FRP bars markedly enhances the flexural strength of concrete beams. Increasing the number of layers from four to five further boosts this strength, indicating a positive correlation between the number of reinforcement layers and flexural strength. The stark contrast with the unreinforced beams underscores the effectiveness of using PP and basalt FRP bars in improving the structural performance and load-bearing capacity of concrete beams.

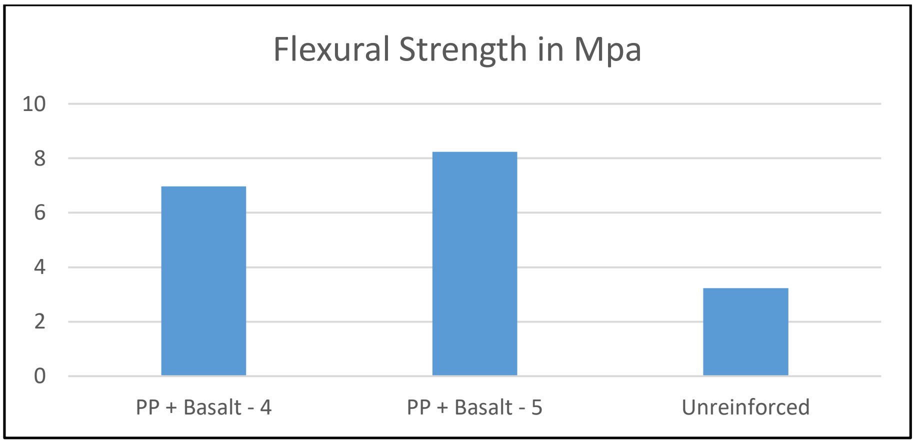

Figure 4.43 Comparison of BCRwith unreinforced beam for flexural strength

4.7.5 Nylon + Basalt BCR

Table 4.38 & Figure 4.44 present a comparison of the flexural strength between concrete beams reinforced with Nylon + Basalt braided rebars and those that are unreinforced. The data indicates that beams reinforced with Nylon + Basalt fourth layers have a flexural strength of 6.41 MPa, which is an increase of 98.70% over the unreinforced beam’s strength of 3.226 MPa. Similarly, beams with Nylon + Basalt fifth layer reinforcement exhibit strength of 7.479 MPa, marking an increase of 131.86% compared to the unreinforced beam. These results underscore the substantial enhancement in flexural strength provided by the Nylon + Basalt braided rebars. The significant improvements in flexural strength for both the 4 and 5 layers of reinforcement affirm the efficacy of Braided BCR in bolstering the structural integrity and durability of concrete beams, offering a robust alternative for construction projects that demand increased strength and extended service life.

Table 4.38 Comparison of BCR with unreinforced beam for flexural strength

Material	Layer	Flexural Strength (MPa)
Nylon + Basalt	Fourth	6.41
Nylon + Basalt	Fifth	7.479
Unreinforced Beam	--	3.226

This data clearly demonstrates that the hybrid reinforcement with nylon and basalt FRP bars significantly boosts the flexural strength of concrete beams. The increase in the number of layers from four to five further enhances this strength. The comparison with the unreinforced beams highlights the substantial improvement in structural performance and load-bearing capacity achieved through the use of combined BCR reinforcement.

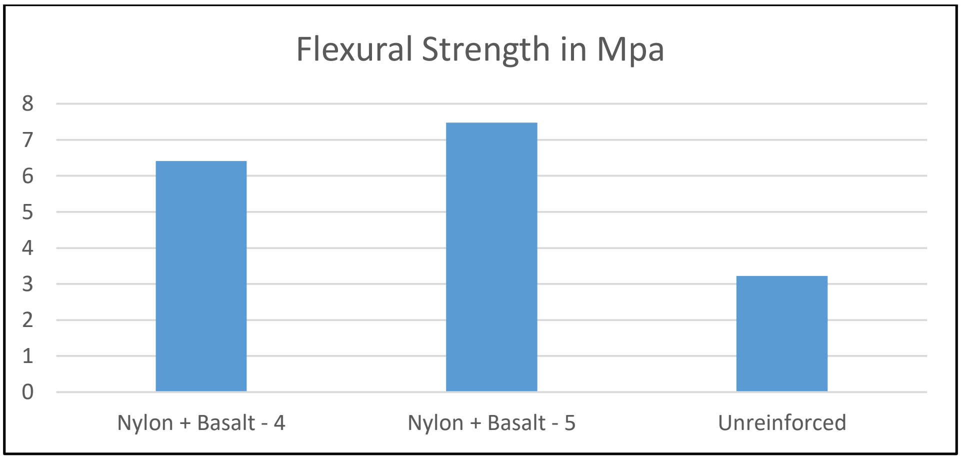

Figure4.44 Comparison of BCR with unreinforced beam for flexural strength