

Tensile Properties characterization of Glass and Jute Fabric-based Hybrid Composites and Applications in Engineering

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Abstract

Composites have an exceptional prospective to replace traditional metals like steel and aluminium by offering low weight, high strength, excellent damping characteristics and outstanding performance at elevated temperatures. Jute composites are emerging significantly and are being used in the formation of green composites materials. In this study, glass-jute hybrid composites, prepared through hand layup techniques, were used with different layers of glass and jute fiber. The tensile test carried out on these composite materials was according to ASTM D3039 standard. The experimental results stipulate that the tensile properties of Glass Fiber Reinforced Polymer (GFRP) were not affected by the mixing of jute fiber in it. Also, the strength of single layer jute fabric with glass layers and GFRP composites was found out to be almost the same. Furthermore, the hybridization of jute fiber with glass fiber could improve its tensile properties. In addition to this, a numerical simulation using ABAQUS was performed, and an error of nearly 4% was found between the results obtained using numerical and experimental approaches. The error may have been resulted due to the non-uniformity in diameter of jute fiber. Moreover, to find the interfacial strength of the material, Fractography was performed on OLYMPUS Microscope. The results obtained from this analysis indicates that more pull out of jute fabric in high jute weight percentage composites is the leading cause of its lower tensile strength. The benefits of hybrid composites could be seen in many engineering and structural applications including skateboard, hockey and automobile's interior and exterior parts.

1. Introduction

The seminal discoveries in the area of materials engineering resulted advanced materials known as "composites". Traditionally, in these materials synthetic fibers are used as a reinforcement. However, natural fibers are becoming increasingly popular and are replacing synthetic fibers as a reinforcement, since these are more eco-friendly and economical [1–3]. Moreover, natural fibers possess adequate strength, bio-degradability, lightweight, and can be processed quickly[4]. The conventional materials like glass, carbon, and Kevlar fibers have extravagant prices, and the utilization of these fibers is legitimized distinctly in aviation and military applications only [5–6]. Among current natural fiber materials, Jute fibers are widely being used as reinforcement in hybrid composites [7]–[9]. Jute is also in the second position in the economic ranking succeeding cotton [10]. The Jute-coir based composites are widely used in railway coaches for sleeper berth backing, packaging market, cloth, and sacks. The natural jute fibers based composites are seen extensively in many automobiles parts, furniture equipment, storage of agricultural products, sports goods, and many chemical products [11]. There are plethora of experimental [12–18] and a few numerical techniques [19–21] for the mechanical characterization of Natural Fiber-Reinforced Composite (NFRPC) materials or only Natural Fiber Composites (NFC). These numerical techniques can successfully predict the mechanical properties of NFC and different synthetic fibers reinforced composite within an acceptable error range [19–20][22].

Rafiquzzaman et al. used hand layup technique for the manufacturing of skateboard and showed that the jute-glass fibre (JGF) based polymer skateboard has a maintainable quality over Canadian hard rock

maple wood for the application in building sportswear part. The cost analysis of this study indicated that around 20% of the cost dropped, by using JGF as a material for the manufacturing of the skateboard [5]. S.K. Acharya et al. studied the tribological behavior of hybrid glass-jute composites under different stacking sequence and found that the hybrid composite with 40% jute fiber and 60% glass fiber have higher wear resistance than other hybrid composites. The results highlighted that an optimal percentage of jute-fiber can ameliorate the wear resistance [23].

Bandaru et al. performed Experimental and numerically study on thermoplastic Kevlar-Basalt composites for studying the effects of hybridization. Simulation results were higher as of experimental results [19]. Rafiquzzaman et al. experimentally and numerically investigated the glass-jute hybrid composite laminates. In numerical analysis, the individual composite plates were joined together to represent the whole model and an error of nearly 20% was observed between experimental and numerical model. They alluded that this might be due to the presence of voided content in the experimental model as a result of flawed fabrication method [12].

Sudheer M. et al. performed the analytical and numerical study on glass-epoxy structural for the determination of elastic properties. While the models like rule of mixture, Halpin-Tsai Nielsen and Chamis elastic models were used in the analytical study, ANSYS was used for the numerical analysis and a good agreement was found between the two approaches [24]. Nirbhay M. et al. used ABAQUS to explain the FEA simulation of CFRP test specimen for 15 layered laminate. As a result of comparison of this model with experimental model, reasonably good results were obtained. Also, it was observed during the study that cross-ply laminates were more stiffer than the angled ply laminates [25]. In another study, the probabilistic range of tensile properties of jute-polyester were investigated, for the composite laminate, according to ASTM D3039 and it was found that the composites having a thickness of 4.1 mm possess higher tensile strength [26]. A study on glass-jute composites with varying weight ratios of epoxy-jute-glass (69-31-0, 68-25-7 and 64-18-19) showed that the impact energy, tensile and flexural strength increases with the increase in glass content [27]. Sisal-glass fibers reinforced epoxy hybrid laminates were fabricated with two fixed glass layers and varying sisal fiber with different weight ratios (0%, 2%, 4% and 6%). The results obtained from this study highlighted that a combination containing 4% weight ratio of sisal showed highest tensile, flexural and impact properties [28].

Experimental tensile properties were evaluated for different stacking sequence (0/0/0/0, 0/+45/-45/0 and 0/90/90/0), And the first two stacking sequences represented the higher tensile properties [29]. Tensile strength of jute cloth-wool reinforced epoxy was studied, in another study, according to ASTM D3039 and it was observed that the hybridization improves tensile strength [30]. In this study, jute natural fiber was chosen due to its simplicity of production and ease of availability. Different studies conducted in the past [32–34] suggested that glass fibers are the most ordinarily utilized manufactured fibers, owing to their high quality, firmness, low thickness, low cost, high flexibility, and essentially low water digestion rate [35].

The main aim of the study was to find the tensile properties and investigate these hybrid materials which would help to explore many potential applications in sports and engineering field. Furthermore, woven glass and jute fabrics, at particular new stacking sequences, was characterized by using hand layup method [36]. The Experimental tensile results were compared and validated with finite element analysis (FEA) results.. Also, to check the interfacial characteristics of materials, Fractography was performed.

2. Experimental Procedures

2.1. Materials Collection

In present work simple plain, woven E-glass as revealed in Fig. 1 and naturally existing plain-woven jute fabric as revealed in Fig. 2 were used as reinforcement. Epotec YD-128 was used as the matrix. The detail of fibers is provided in Table 1 below.

Table 1
Properties of Fibers

Property	E-Glass Fiber	Jute Fiber
GSM (g/cm ²)	170	230
Yarns count in Warp Directions (per 100 mm)	52	33
Yarns count in Weft Directions (per 100 mm)	50	39

2.2. Preparation of composite

Hybrid composites were fabricated by a simple Hand layup method. The epoxy resin and harden were mixed in 2:1 proportion and stirred manually for twenty minutes to get uniform dispersion. Step-1, initially mold freeing resin is dispersed on glass mold. Step-2, peel ply (material help in removal of final composite from glass mold) was placed above the sprayed surface. Step-3, applying epoxy layer by brush on the first layer of glass and placed on peel ply. Step-4, for even dispersal of epoxy on glass fabric and air bubbles, removal roller was used as shown in Fig. 3. Step-3 and step-4 were repeated to get the desired stacking sequence.

2.3. Mechanical study

After the successful preparation samples were cut according to ASTM D3039 on cutting machine, as shown in Fig. 4, there were four types of hybrid composites as discussed in Table 2 were tested. The tensile test was performed at a strain rate of 2 mm/min and room temperature at 60% relative humidity on the Zwick/Roell Z100 machine. Specimen dimensions were 250mm × 25 mm and thickness was in the range of 1.8 mm to 2.8 mm. Sample during testing is shown in Fig. 5.

Table 2: Samples designations and details

Scheme	Designation	Span Length (mm)	Average Thickness (mm)	Width (mm)
Glass/Glass/Glass/Glass/Glass	GGGGG	150	1.9	25
Glass/ Glass /Jute/ Glass/ Glass	GGJGG		2.1	
Glass /Jute/ Glass /Jute/ Glass	GJGJG		2.4	
Glass /Jute/Jute/Jute/ Glass	GJJJG		2.9	

3. Numerical Analysis

For numerical study ABAQUS selected as a numeric tool due to its higher capabilities as compared to other available software. In step-1, a part is modelled in the first step by taking 3D mesh element. Step-2, glass ply and jute ply are defined in material definition by assigning them orthotropic properties which are discussed in below Table 3 and composite layup is defined in this step. Step-3, assembly is formed in this step, and mesh type is defined. Step-4, analysis step definition is employed in this module. Step-5, interaction is defined in this module; the reference point in the upper grip is coupled with all nodal points in the tensile test model, as shown in Fig. 6. Step-6, boundary conditions are defined in this module lower grip is fixed, i.e. (ENCASTRE $U_1 = U_2 = U_3 = UR_1 = UR_2 = UR_3 = 0$) while the upper grip is displaced by applying displacement load on the reference point. Step-7, in this step, the meshing of the model is done. Step-8, results are viewed after simulating to get a force-displacement diagram.

Table 3: Engineering Constants and their Sources

Engineering Constants	Glass/Epoxy lamina	Jute/Epoxy lamina	Source
Density (kg/m^3)	1286.5	826.07	Experimentally
$E_1=E_2$ (MPa)	7890	3400	Experimentally
E_3 (MPa)	4953	3200	Analytically (ROM)
G_{12} (MPa)	2850[37]	1574	G/epoxy(Literature), J/epoxy(analytically)
$G_{23}= G_{13}$ (MPa)	1795	1536	Analytically (ROM)
ν_{12}	0.03	0.08	Experimentally
$\nu_{23} = \nu_{13}$	0.3	0.32	Analytically (ROM)

4. Discussions

4.1. Tensile Test

As discussed earlier, the tensile test was done as per ASTM D3039 standard. Different samples containing jute and glass in different percentages were tested, and their results are described in the bar chart. The combination GGGGG possess a higher tensile strength of 87 MPa, and the combination GGJGG possess a tensile strength of 82 MPa. The difference between the tensile strength of GGGGG and GGJGG sequence is almost negligible Showing that the replacement of jute fiber with glass fiber in GGGGG sequence does not affect its tensile strength. So, jute has potential to replace glass fiber without significant loss in tensile strength, and the effect of hybridization can improve tensile properties [13],[27]. Whereas combination GJJJG possesses the lowest tensile strength of 43 MPa. It was found that by increasing significant jute percentage in GFRP composite decreases tensile strength is decreased. It is due to glass fiber has higher mechanical properties than jute fiber.

Also, the possible reason for GGGGG and GGJGG sequence has higher tensile strength is due to the minimum interface layers at which adhesion is applied. At the interface, if there are two dissimilar materials, there is a chance of breakage due to poor bonding between these materials. The combinations GJGJG has maximum no. of interface layers which decreases its tensile strength however the combinations GJJJG has adhesive layer similar to GGJGG sequence. However, lower strength of GJJJG sequence is due to majority portions of jute fiber which decreases its tensile strength. Stress-strain curves for all the stacking sequences shown in Fig. 7. The calculated average Young's/Elastic modulus and percentage strain at failure from stress-strain curves for different sequences are reported in Table 4. The bar charts for tensile strength is shown in Fig. 8.

Table 4 Calculated Engineering Constants from Stress-strain Curves

Specimens Type	Scheme	Ultimate Tensile strength (MPa)	Average Elastic Modulus (MPa)	Average Strain (e) at failure (%)
Glass/Glass/Glass/Glass/Glass	GGGGG	87	7890	1.6
Glass/ Glass /Jute/ Glass/ Glass	GGJGG	82	5516	2.0
Glass /Jute/ Glass /Jute/ Glass	GJGJG	52	3947	1.8
Glass /Jute/Jute/Jute/ Glass	GJJJG	44	3193	2.2

4.2. Numerical

A minimum error of 4% between experimental and numerical results is found for GGGGG sequence. This error is increase with increasing jute percentage. A maximum error of 15% is found for GJJJG sequence. This variation in results has many reasons like

- Waviness of fiber

- Hand layup techniques
- Jute fiber non-uniformity in properties distribution

Due to waviness fibers tend to straighten themselves and thus bears tensile and shear stresses.

The primary cause of the error is the hand layup technique which causes non-uniform epoxy distribution and void contents that causes stress concentration. Jute fiber shows non-uniform property distribution as in a reinforcement jute dia. varies from fiber to fiber due to local market and substandard processing. The stress contours plots for different sequences are shown in Fig. 9. The comparison of force vs displacement graphs for these sequences is shown in Fig. 10.

4.3. Microscopic/Fractographic Evaluation

Microscopic evaluation was done on an Olympus metallurgical microscope. Pictures of broken samples were studied under different sights. It was found that all samples exhibited a mixed failure pattern. Figure 11 demonstrates the failure mechanism for GGJGG sample. In which jute fiber shows the more elongations. This pattern is due to cohesive failure within the adhesive resin. Figure 12 illustrates glass fiber early breakage in GJGJG sample. It is due to glass fiber low elongation as compared to jute fiber. Fractured specimen of GJGJG sequence from a side position is shown in Fig. 13. Jute fiber pulls out in GJJJG sequence is observed in Fig. 14. It is due to jute fiber has poor adhesion with matrix/epoxy, and when the load is applied, these fibers pulls out from the matrix.

5. Applications Of Glass And Jute Hybrid Composites

Under the concern of global climate change and progress in the field of biodegradable materials now led us to use these materials as an alternative to synthetic materials such as GFRP and other synthetic fiber-based composites. Glass/Jute fiber based green composites are, for the most part utilized in a car (interior and as exterior parts) and construction industries. Some applications of glass and jute composites in engineering are discussed in Table 5 below.

Table 5
Applications in engineering [5], [38]–[45]

Applications	Glass Composite	Jute Composite	Glass/Jute Composites
Automotive Industry	Oxygen tanks, and power transmission shafts	Trim parts seat cushion (Brazilian Trucks)	Automobile front parts and doors
	Printed Circuit boards	In automobile vibration absorber parts	
Sports Industries	Hockey	Hockey, Tennis Racket	Skateboard
Furniture Industries	Inner house decoration and furniture	Doors knobs and Chairs	Roof Ceiling and Cupboards
Others	Bone plates for fracture fixation, implants, and prosthetics	Bottles	Wind turbine blades
	Step ladders and orthodontic appliances		

6. Conclusions

In this study, glass-jute hybrid composites were prepared through hand layup techniques with different layers of glass and jute fiber. The tensile test performed on these composite materials was according to ASTM D3039 standard. The experimental results indicate that the mixing of jute fiber in glass fiber reinforced polymer (GFRP) composite do not affect its tensile properties and the strength of single layer of jute fabric with glass layers and GFRP composites were nearly equal. While improving the tensile properties, the hybridization of jute fiber with glass fiber cuts down a substantial amount of the material cost. To validate the results of the study, a numerical simulation was performed using ABAQUS and an error of approximately 4% was found between numerical and Experimental results. The error may be resulted due to the non-uniformity in the diameter of jute fiber. Fractography was performed on OLYMPUS Microscope to find interfacial strength of the material and the results of this analysis explained that more pull out of jute fabric in high jute weight percentage composites is the leading cause of its lower tensile strength.

A potential scope exists for future researchers to investigate the current study into further analysis like thermal and dynamic mechanical properties. Further study will also be performed to evaluate mechanical parameters using other natural fibers with different manufacturing techniques like Resin Transfer Molding (RTM) and injection molding under different strain rates.

Declarations

Availability of data and materials

Data will made available on request.

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Competing Interest

The authors declare that they have no conflict of interest.

Authors' contributions

Conceptualization, Z.A. and M.Y.K.; methodology, H.A. and M.F.S.; validation, M.Y.K.;

format analysis, Z.A.; investigation, M.A.N and M.F.S.; writing—original draft preparation, M.Y.K.; writing—review

& editing, H.A. and M.Y.K.; project administration, M.A.N. All authors have read and agreed to the published

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Figures

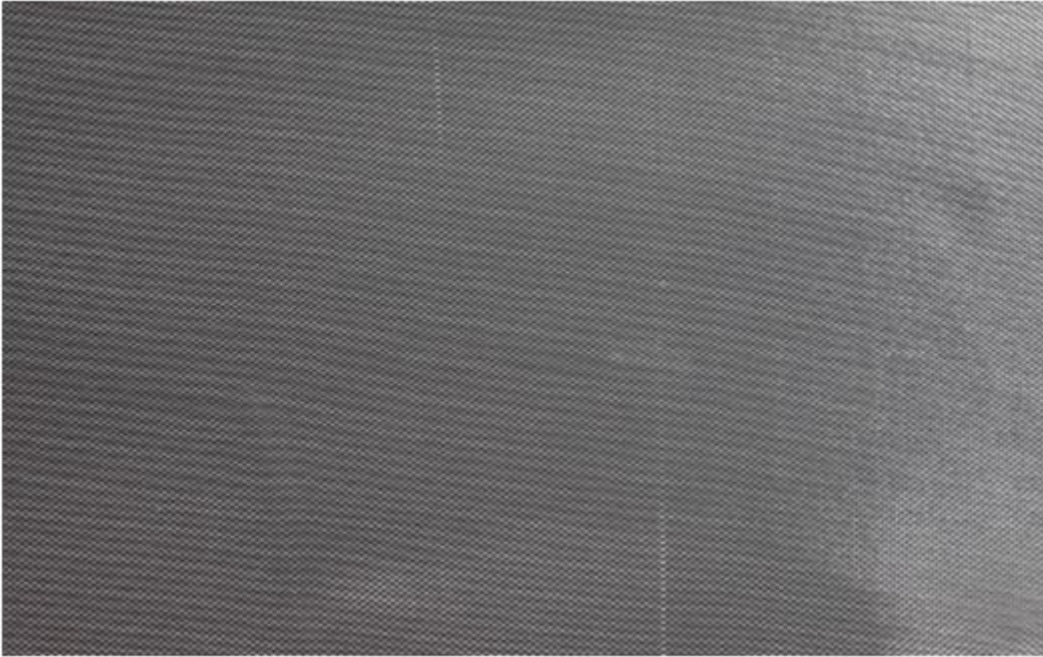


Figure 1

Plain Woven E-glass Fabric



Figure 1

Plain Woven E-glass Fabric

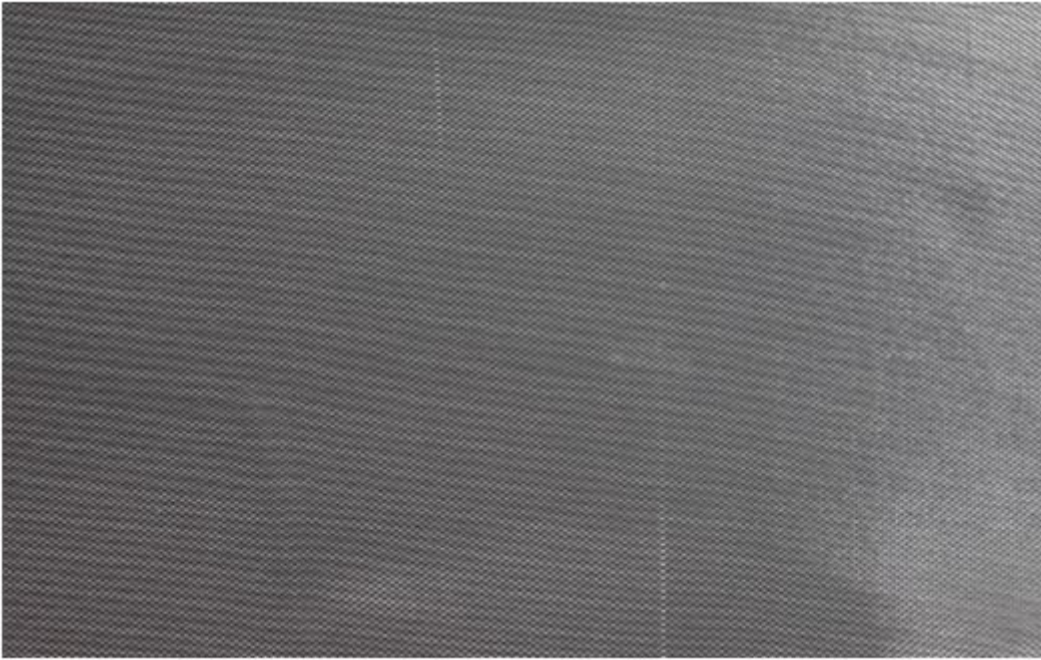


Figure 1

Plain Woven E-glass Fabric

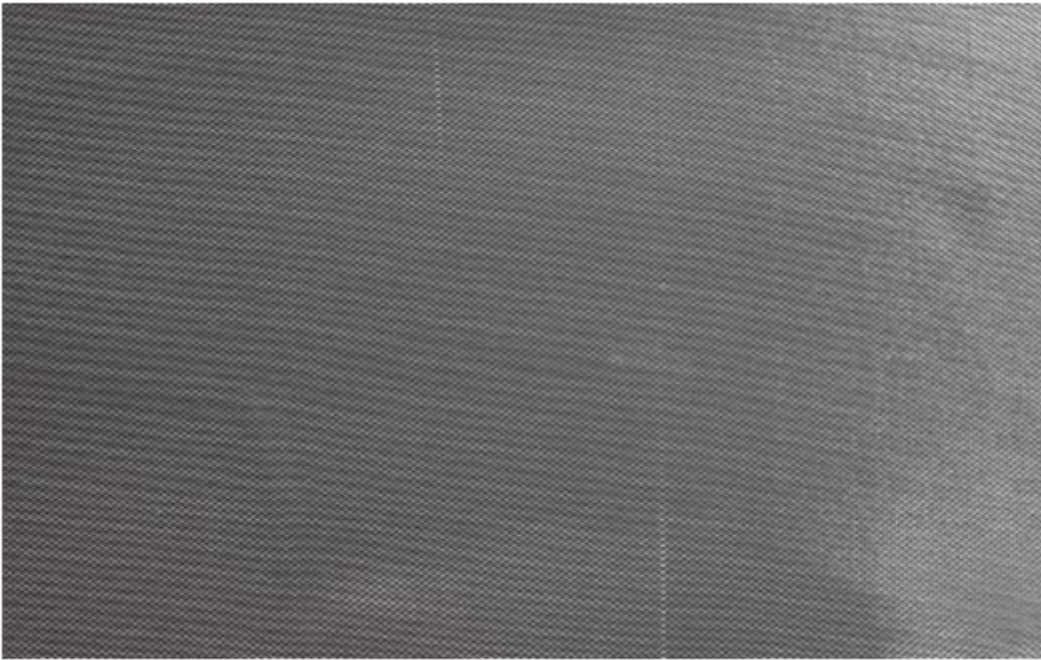


Figure 1

Plain Woven E-glass Fabric

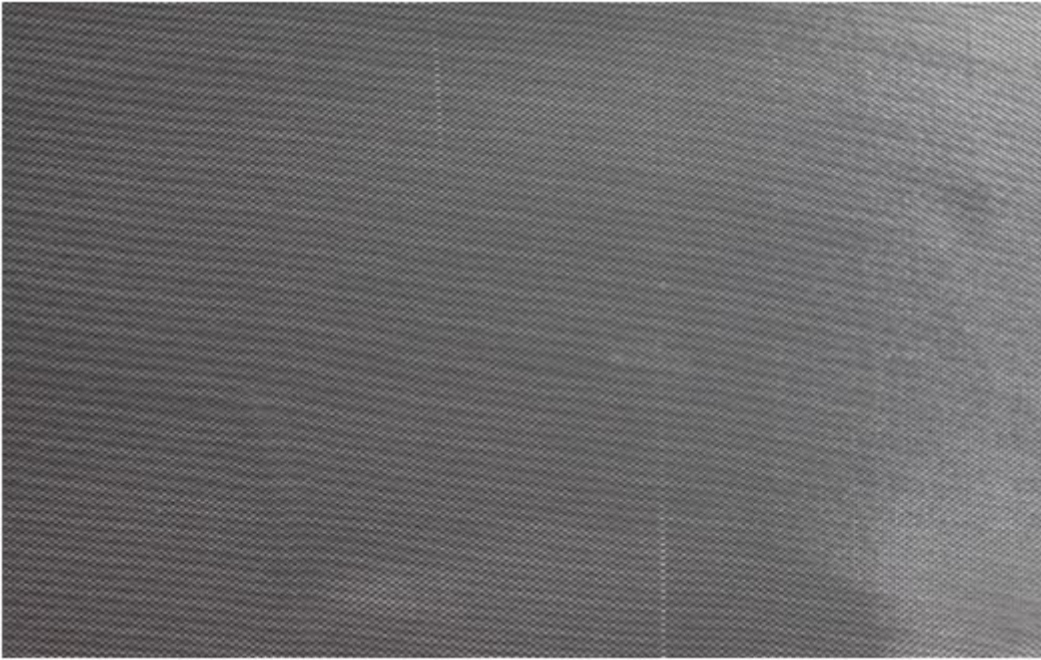


Figure 1

Plain Woven E-glass Fabric



Figure 2

Plain Woven Jute Fabric



Figure 2

Plain Woven Jute Fabric



Figure 2

Plain Woven Jute Fabric



Figure 2

Plain Woven Jute Fabric



Figure 2

Plain Woven Jute Fabric

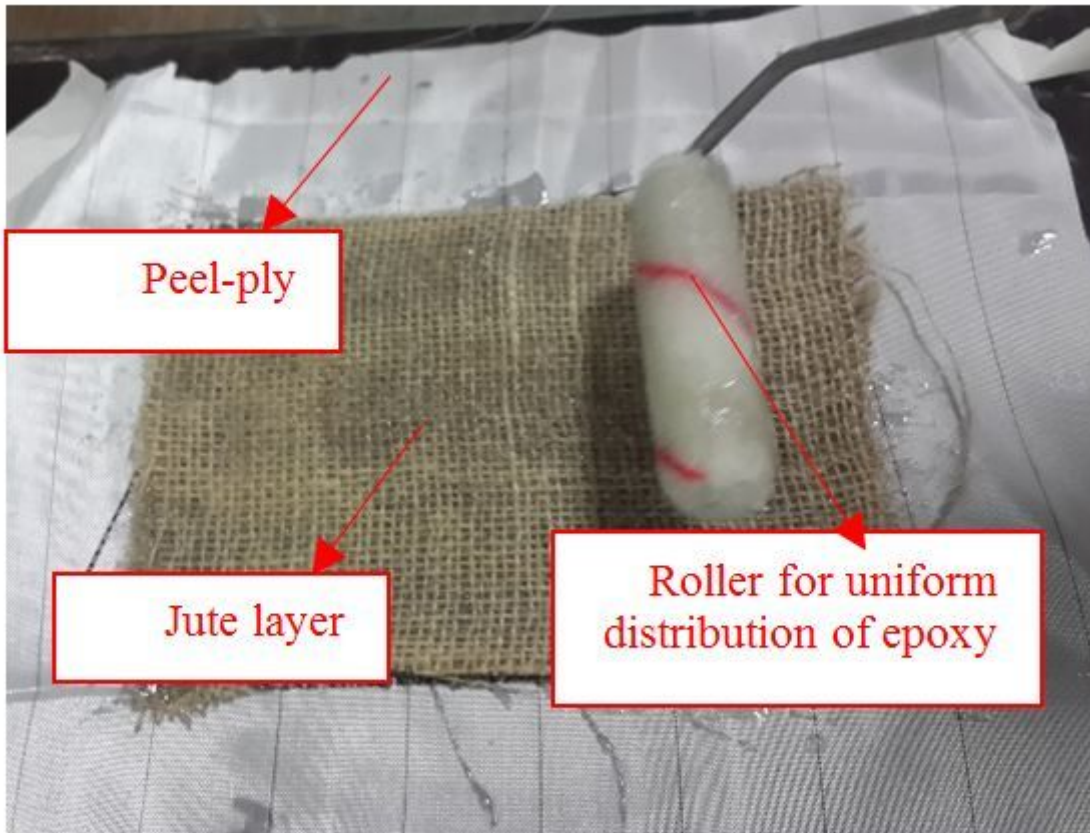


Figure 3

Step 4 illustration

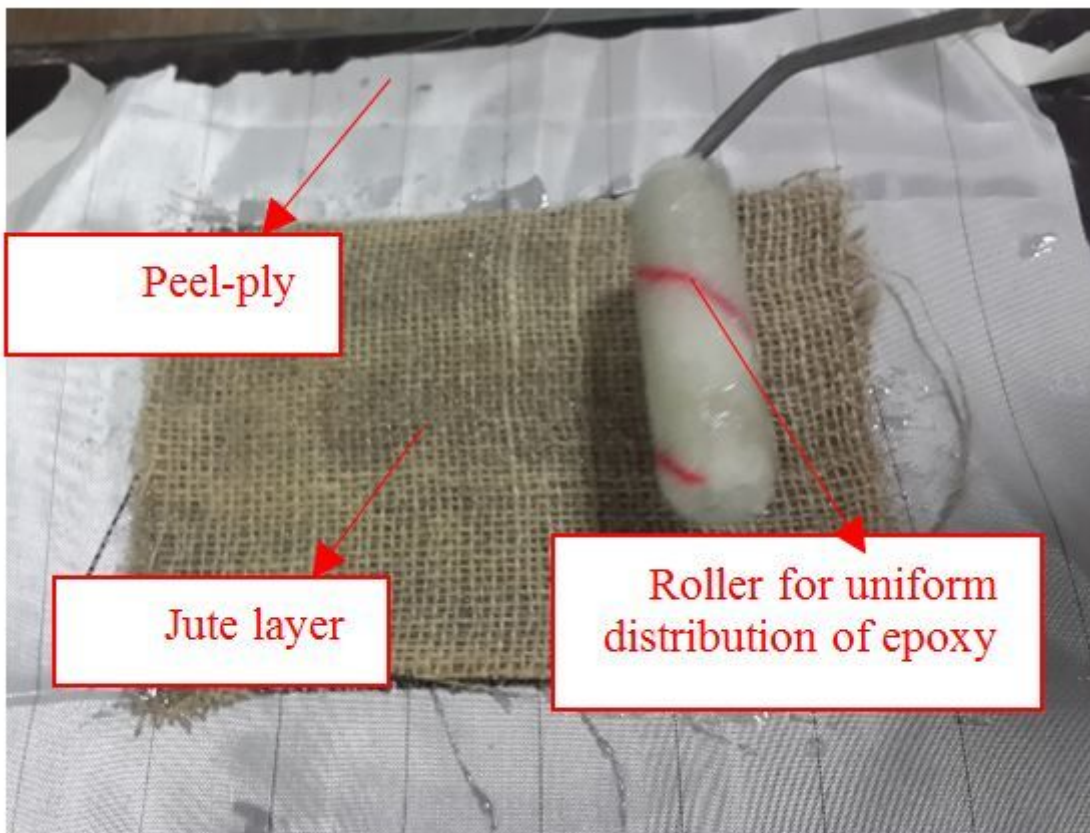


Figure 3

Step 4 illustration

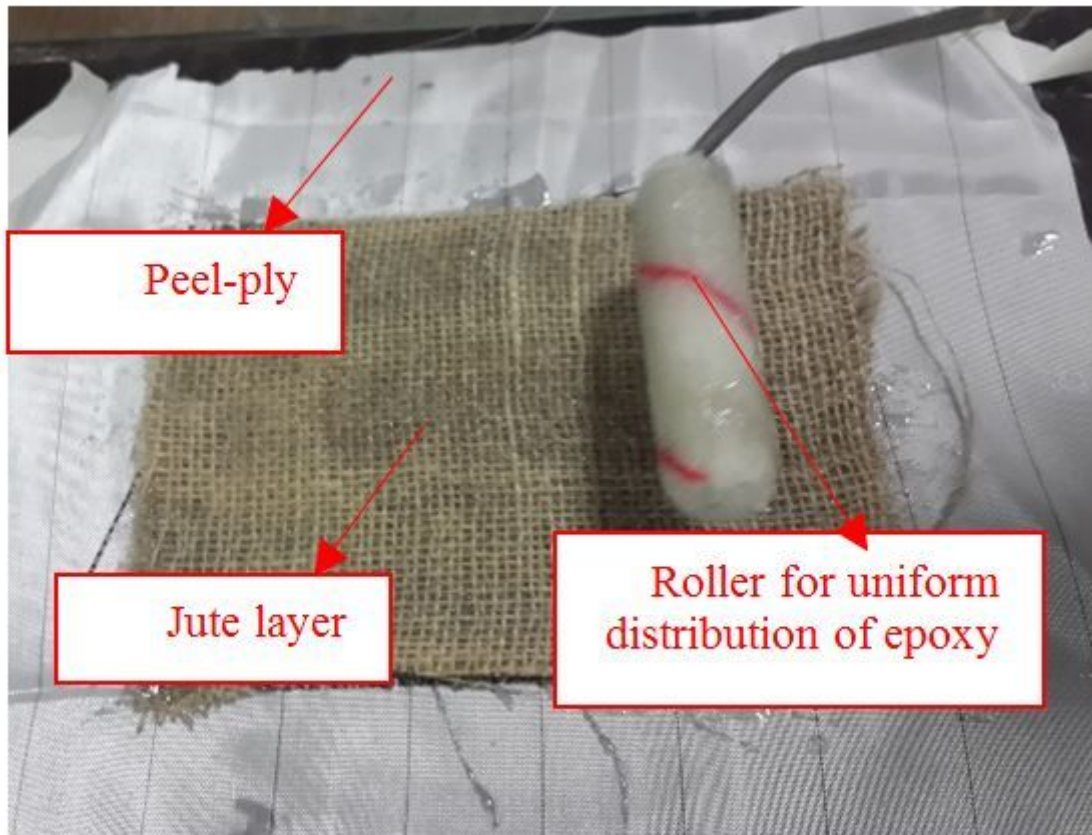


Figure 3

Step 4 illustration

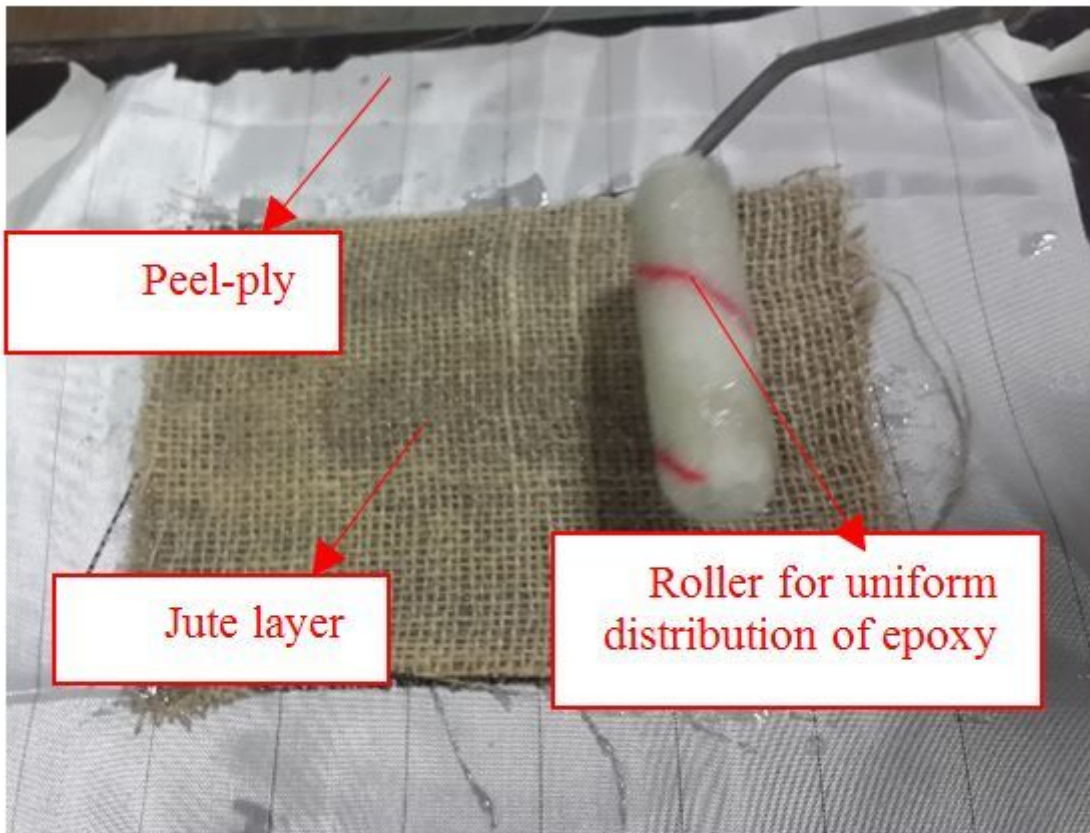


Figure 3

Step 4 illustration

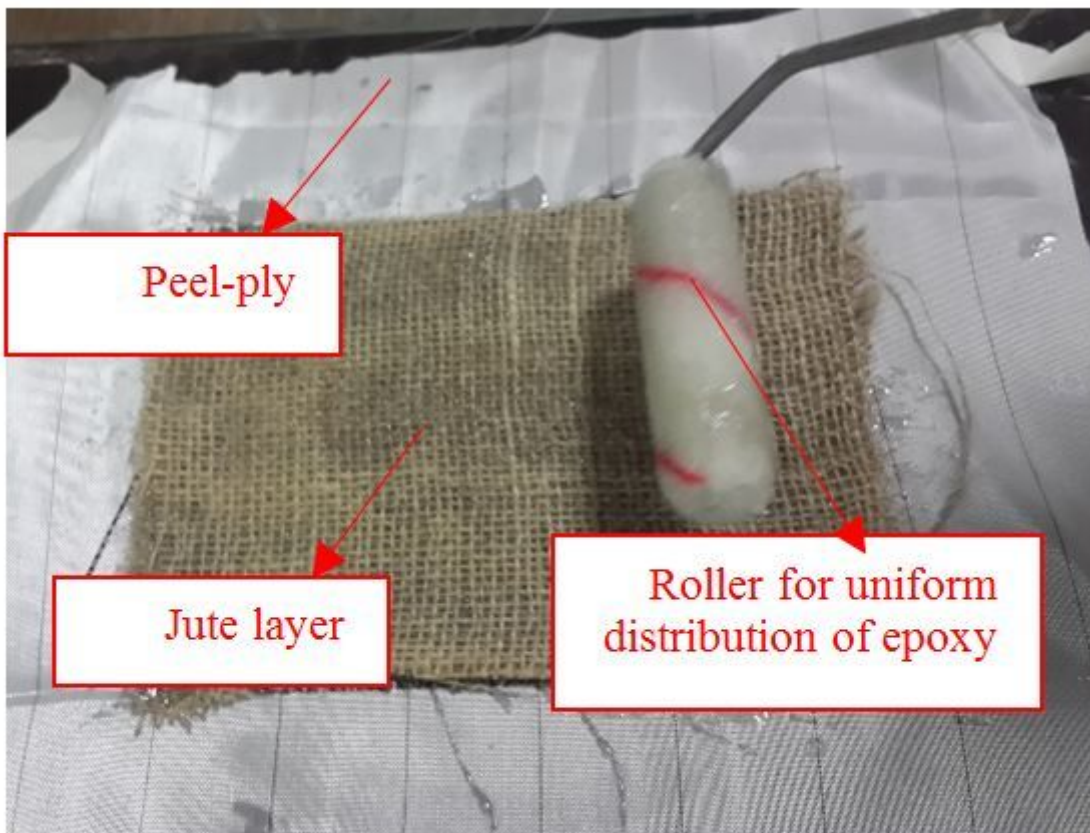
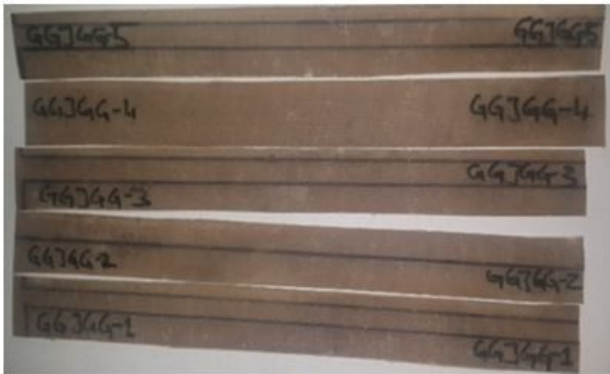


Figure 3

Step 4 illustration



(a)



(b)



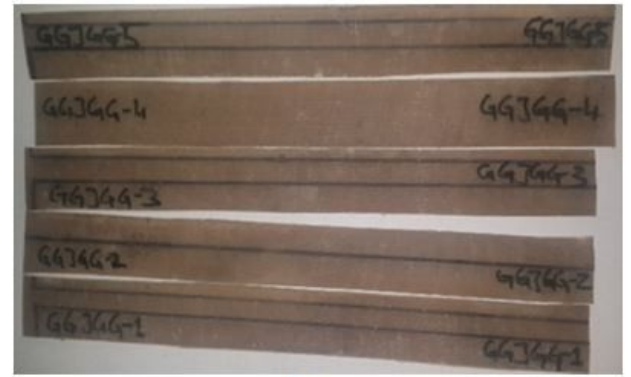
(c)

Figure 4

Hybrid Specimens after cutting (a) GJGJG (b) GGJGG (c) GJJJG



(a)



(b)



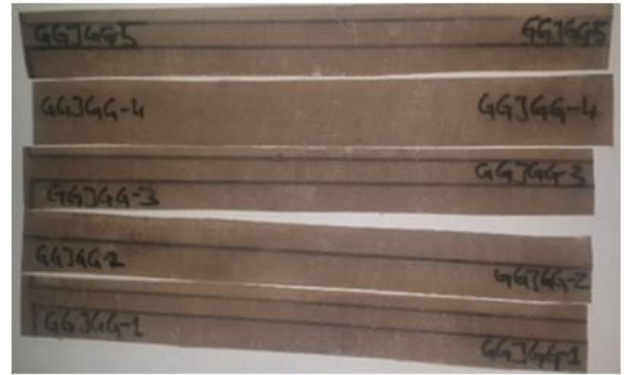
(c)

Figure 4

Hybrid Specimens after cutting (a) GJGJG (b) GGJGG (c) GJJJG



(a)



(b)



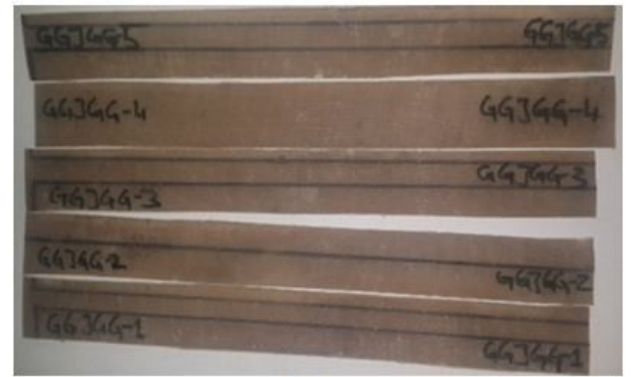
(c)

Figure 4

Hybrid Specimens after cutting (a) GJGJG (b) GGJGG (c) GJJJG



(a)



(b)



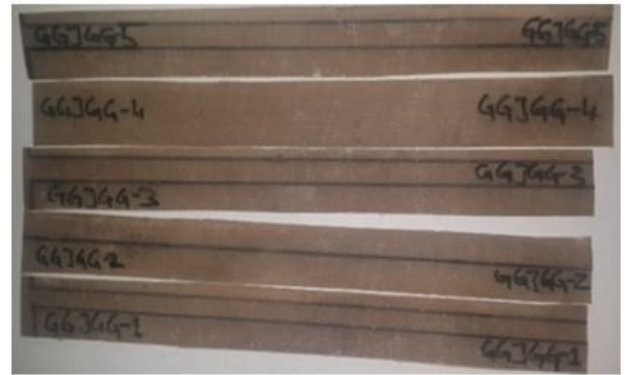
(c)

Figure 4

Hybrid Specimens after cutting (a) GJGJG (b) GGJGG (c) GJJJG



(a)



(b)



(c)

Figure 4

Hybrid Specimens after cutting (a) GJGJG (b) GGJGG (c) GJJJG

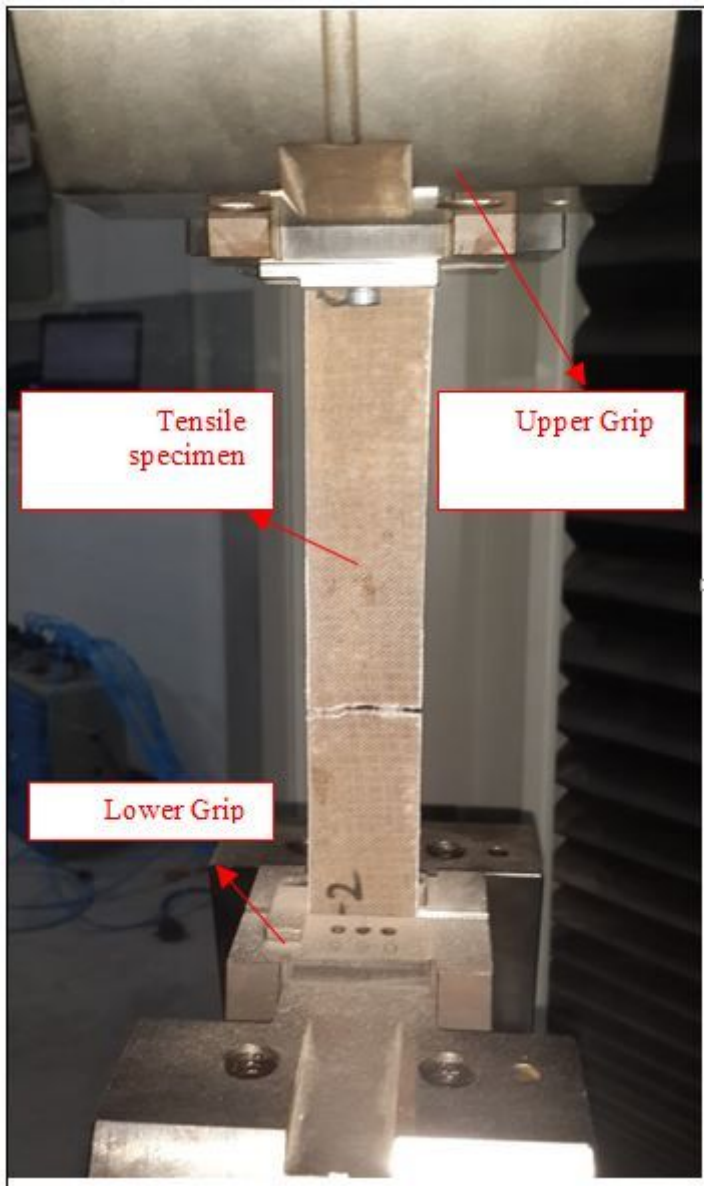


Figure 5

Tensile specimen in the machine

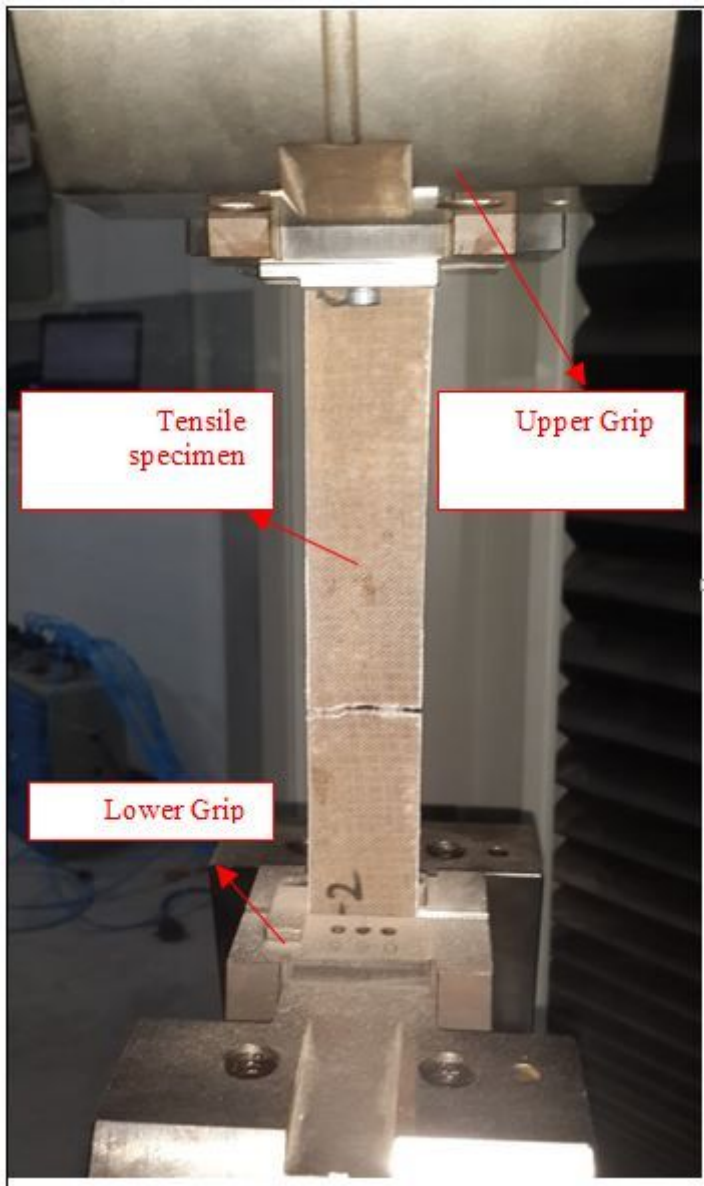


Figure 5

Tensile specimen in the machine

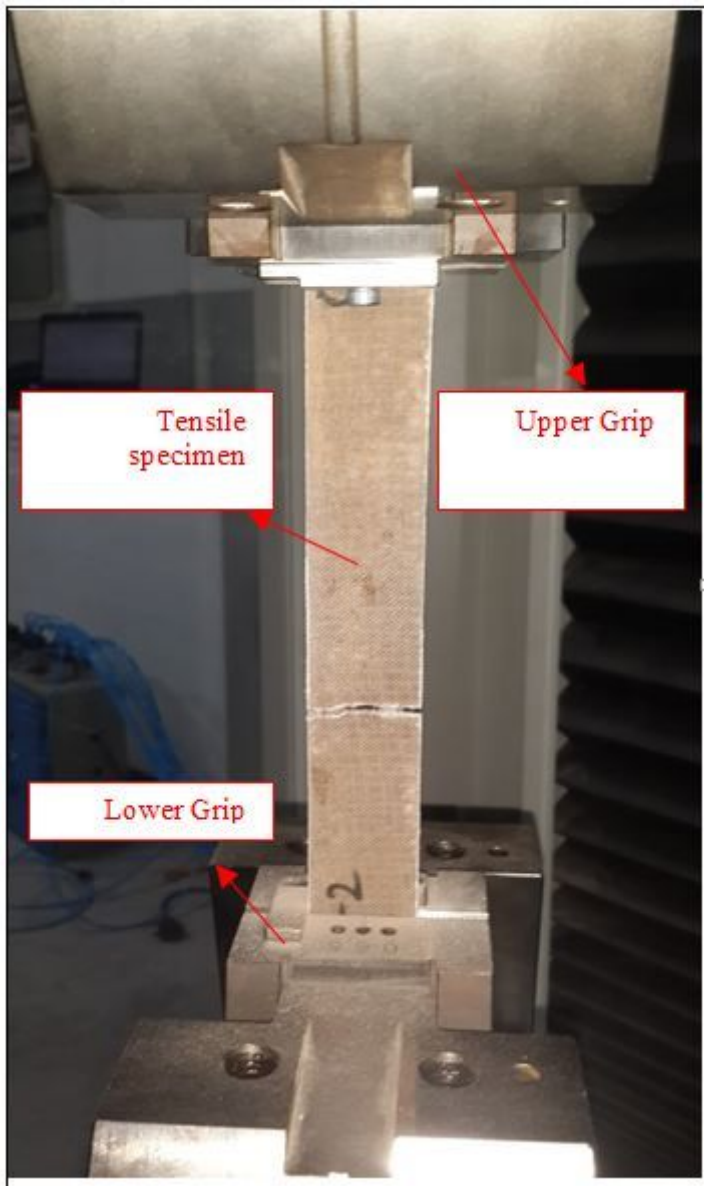


Figure 5

Tensile specimen in the machine

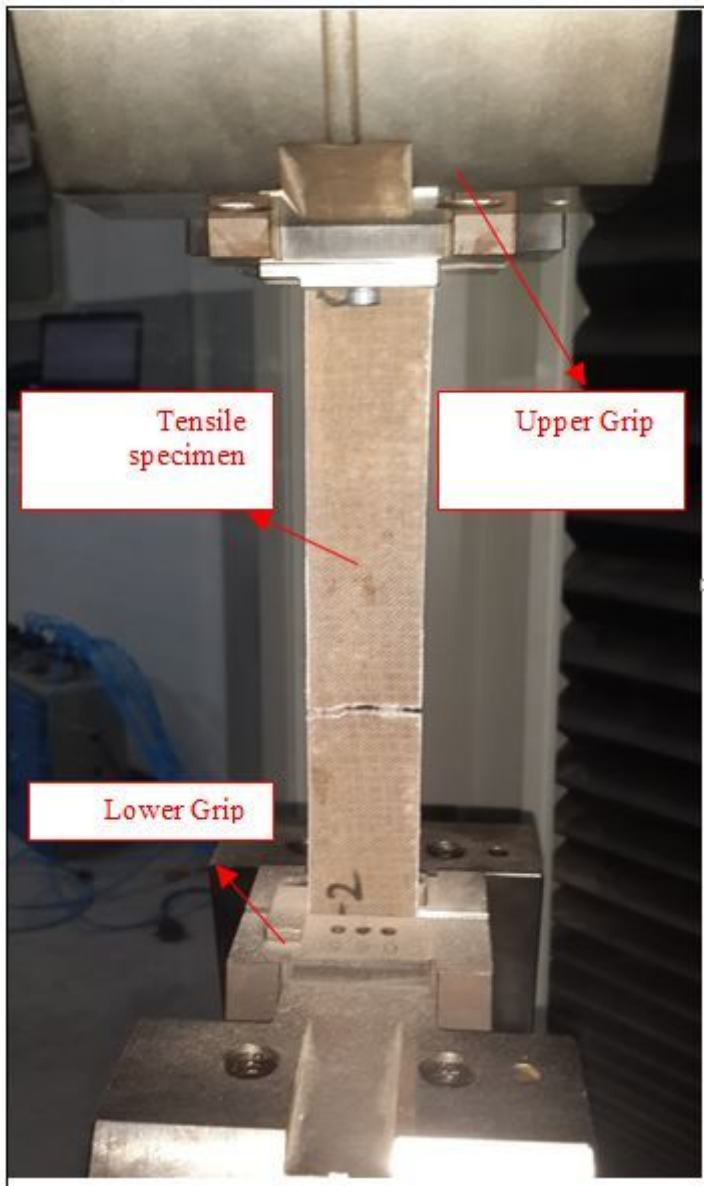


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Tensile specimen in the machine

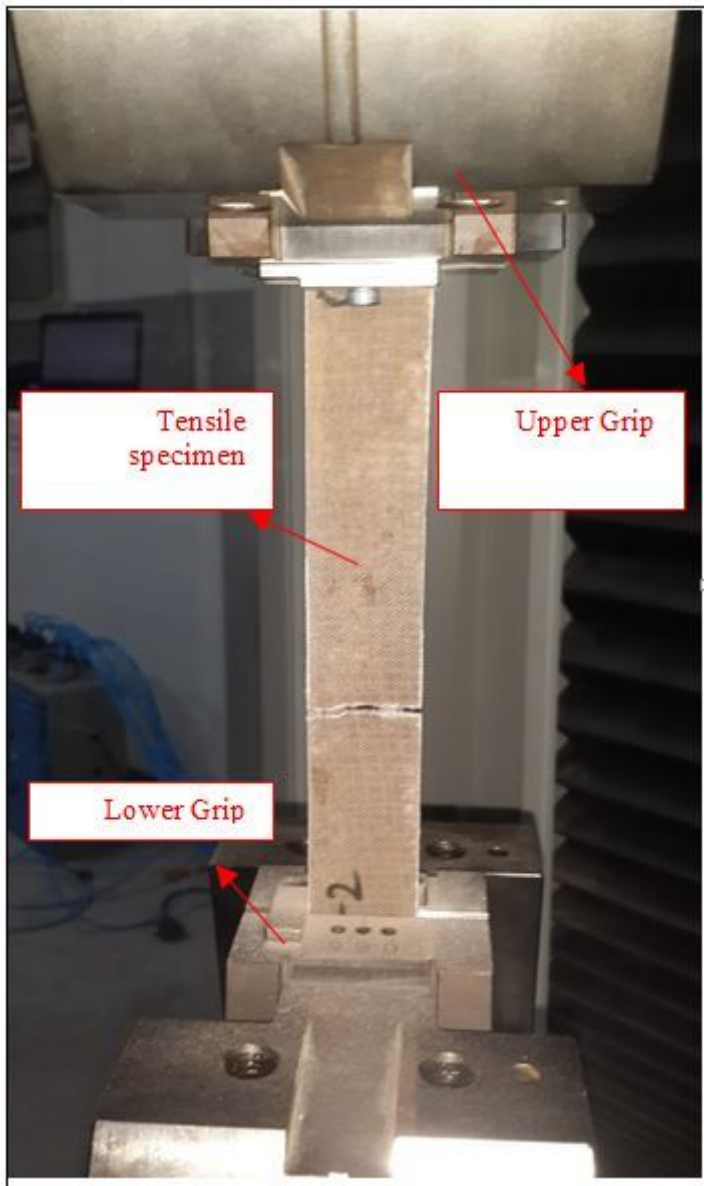


Figure 5

Tensile specimen in the machine

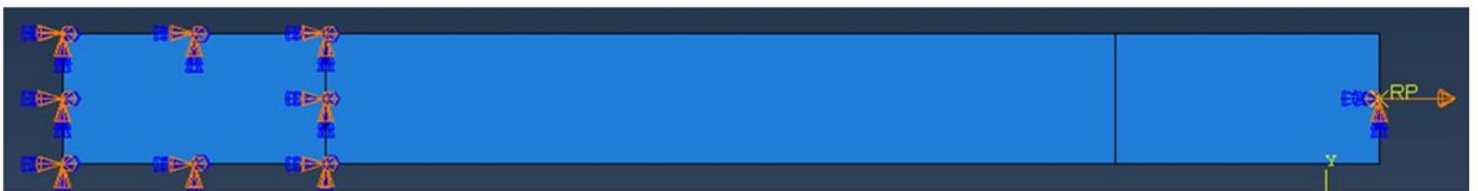


Figure 6

Part Specification

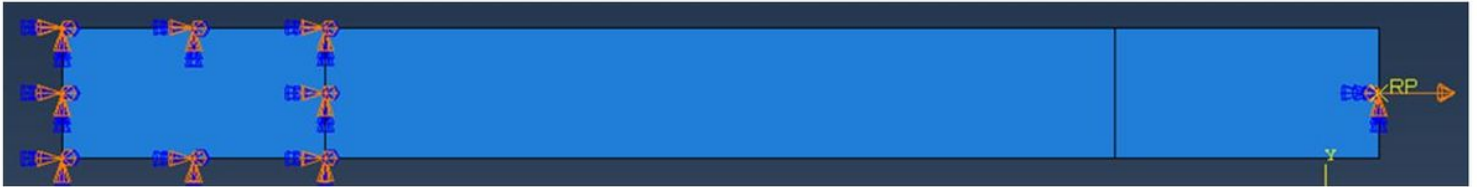


Figure 6

Part Specification

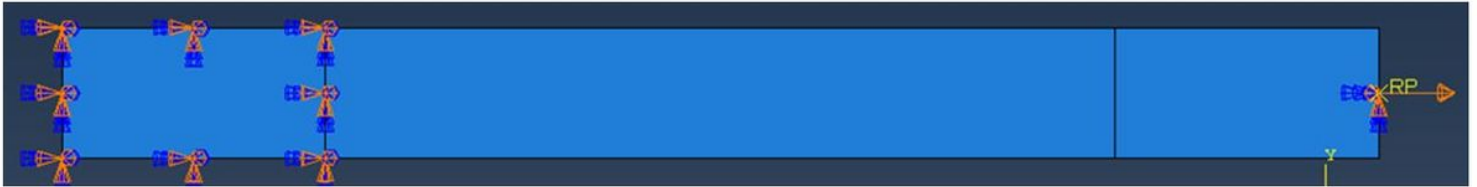


Figure 6

Part Specification

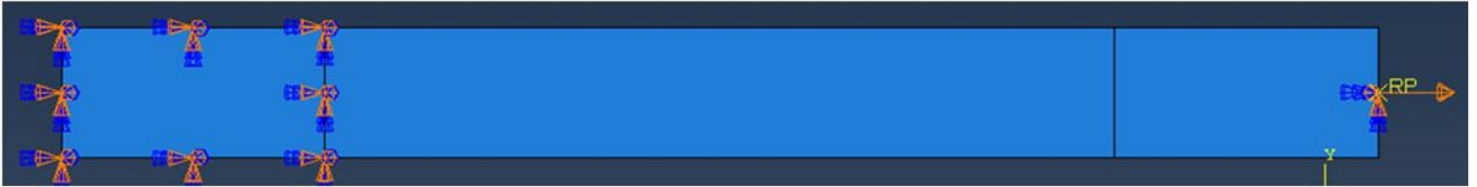


Figure 6

Part Specification

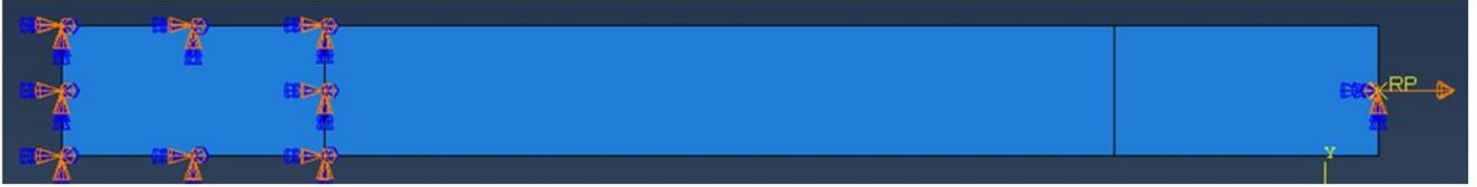


Figure 6

Part Specification

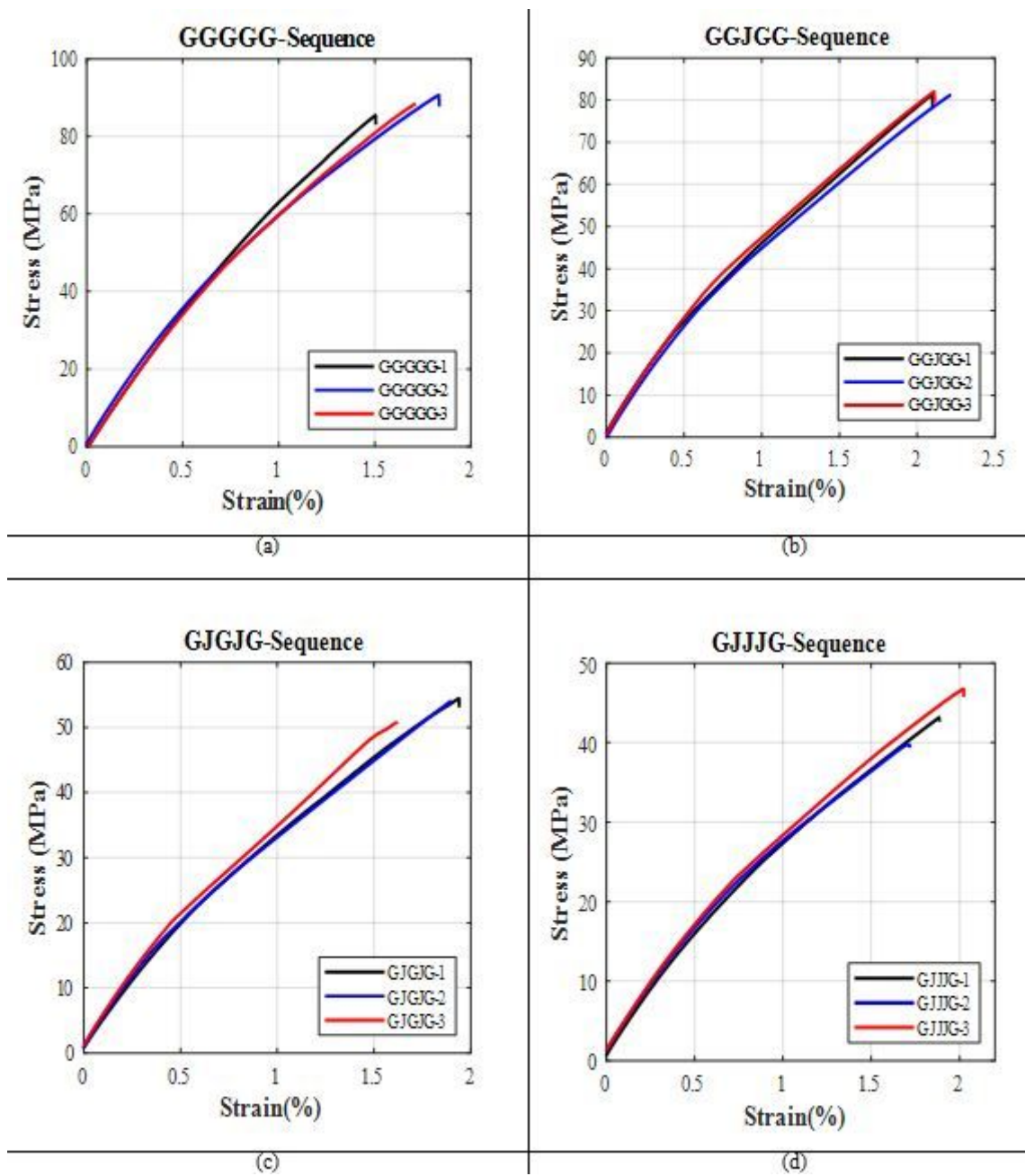


Figure 7

(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence

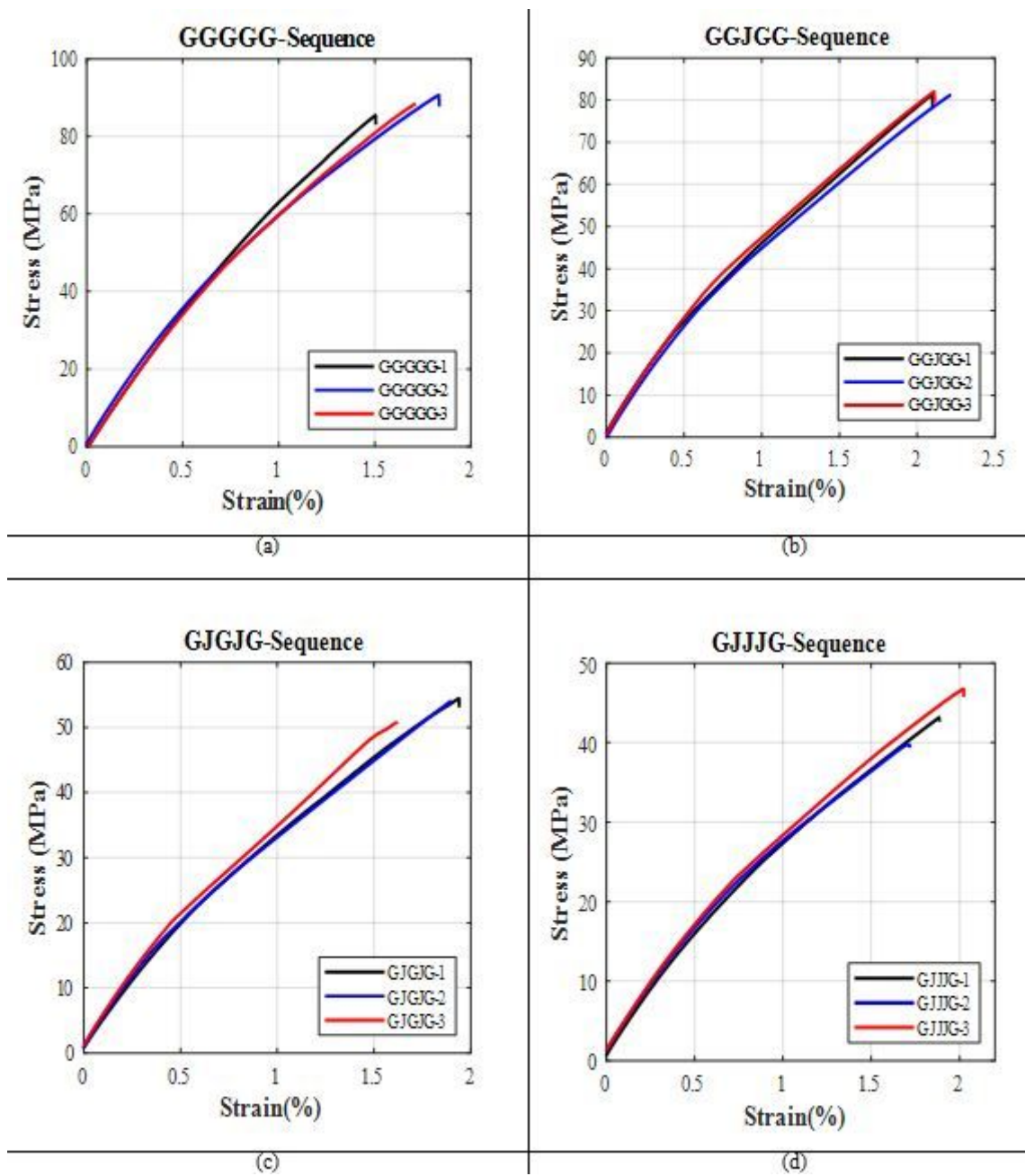


Figure 7

(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence

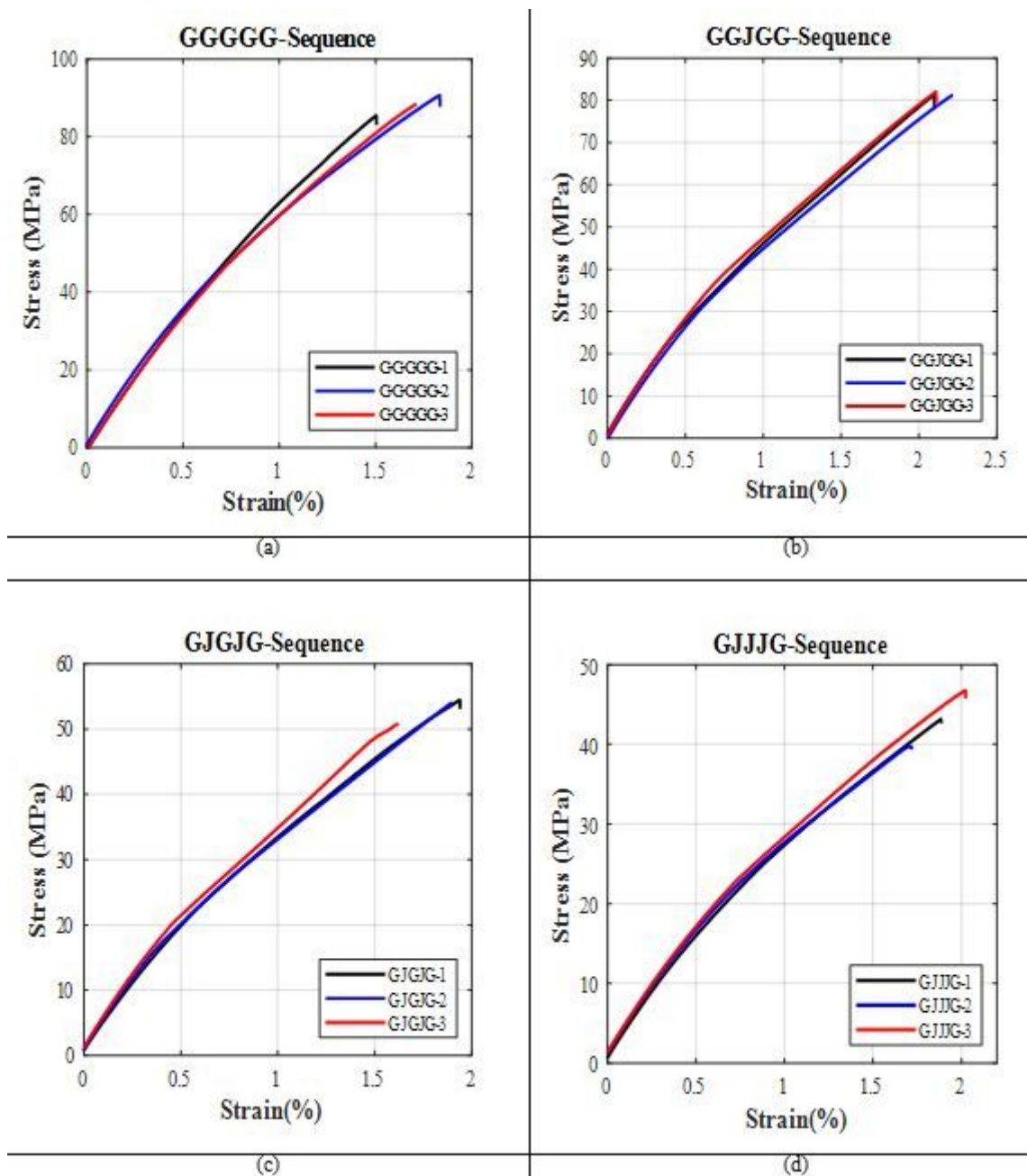


Figure 7

(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence

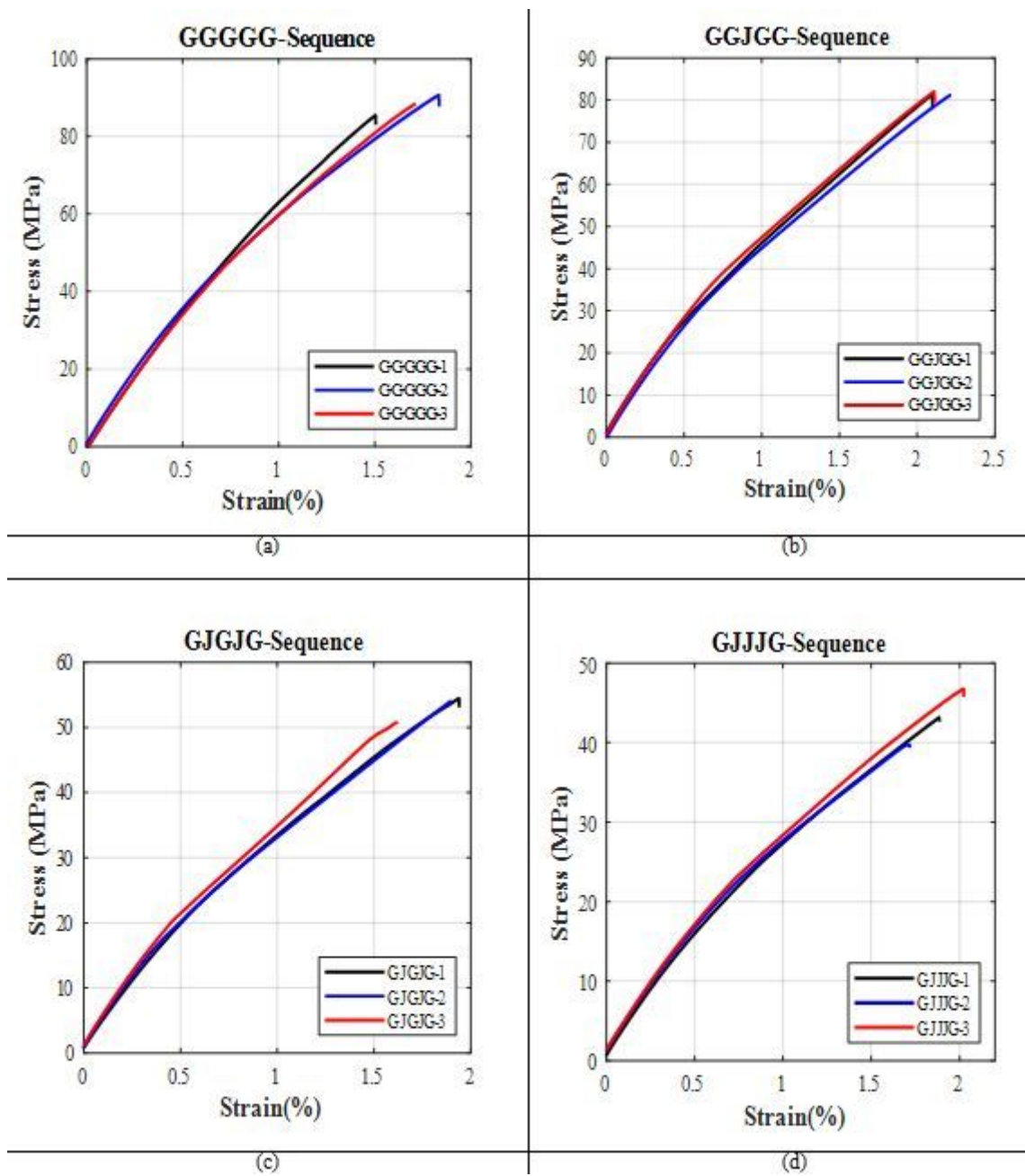


Figure 7

(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence

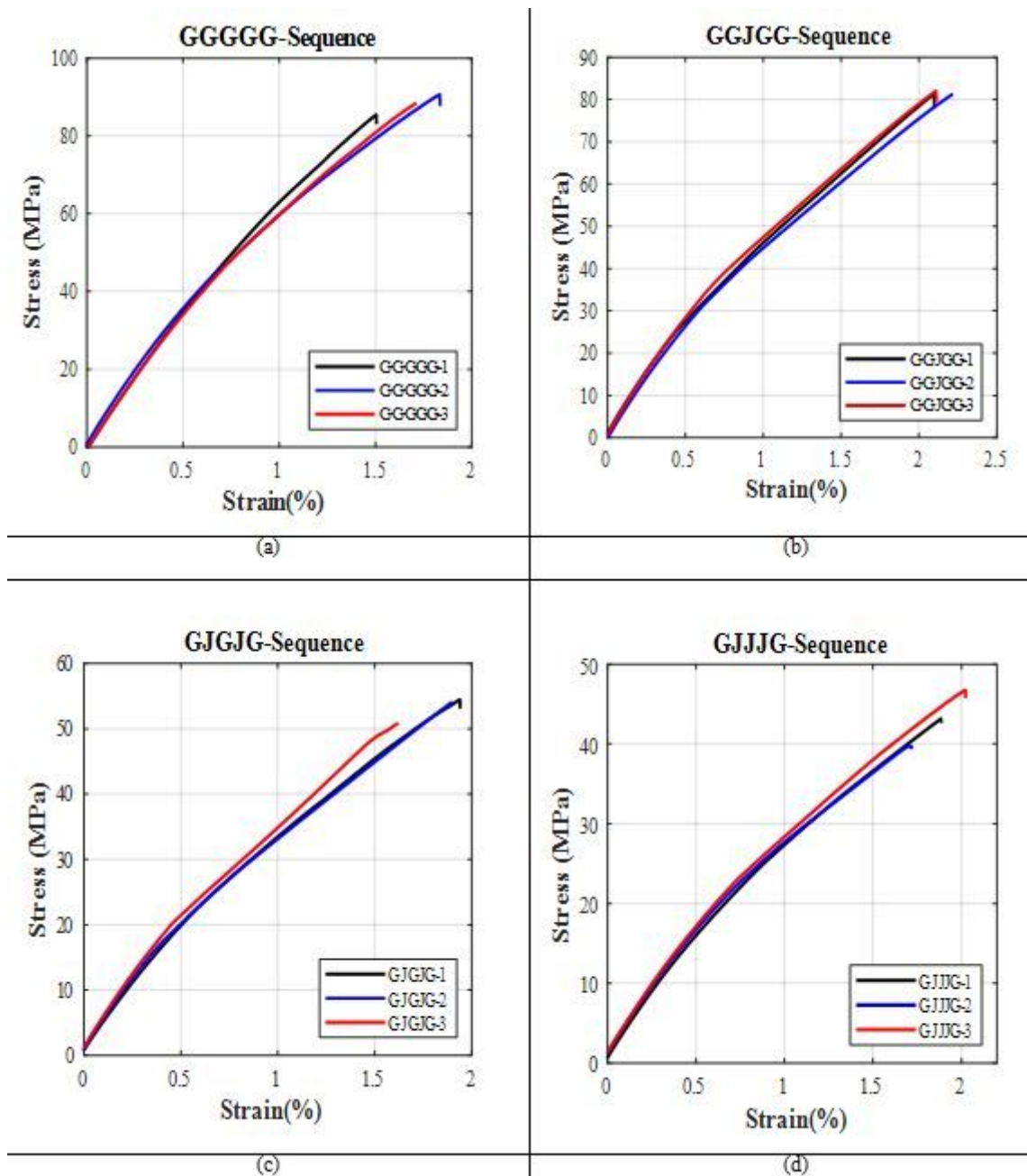


Figure 7

(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence

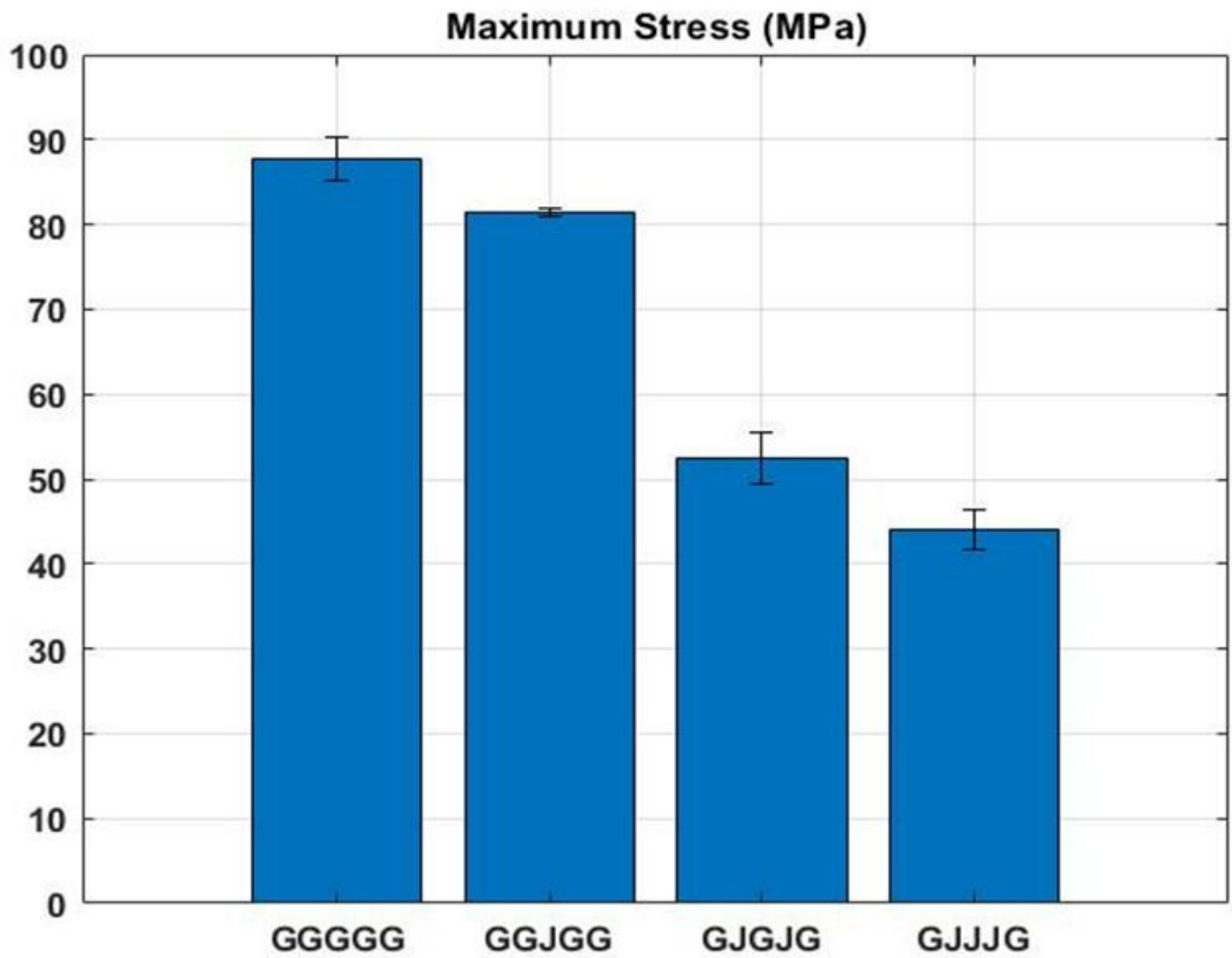


Figure 8

Bar chart of Maximum Tensile Strength

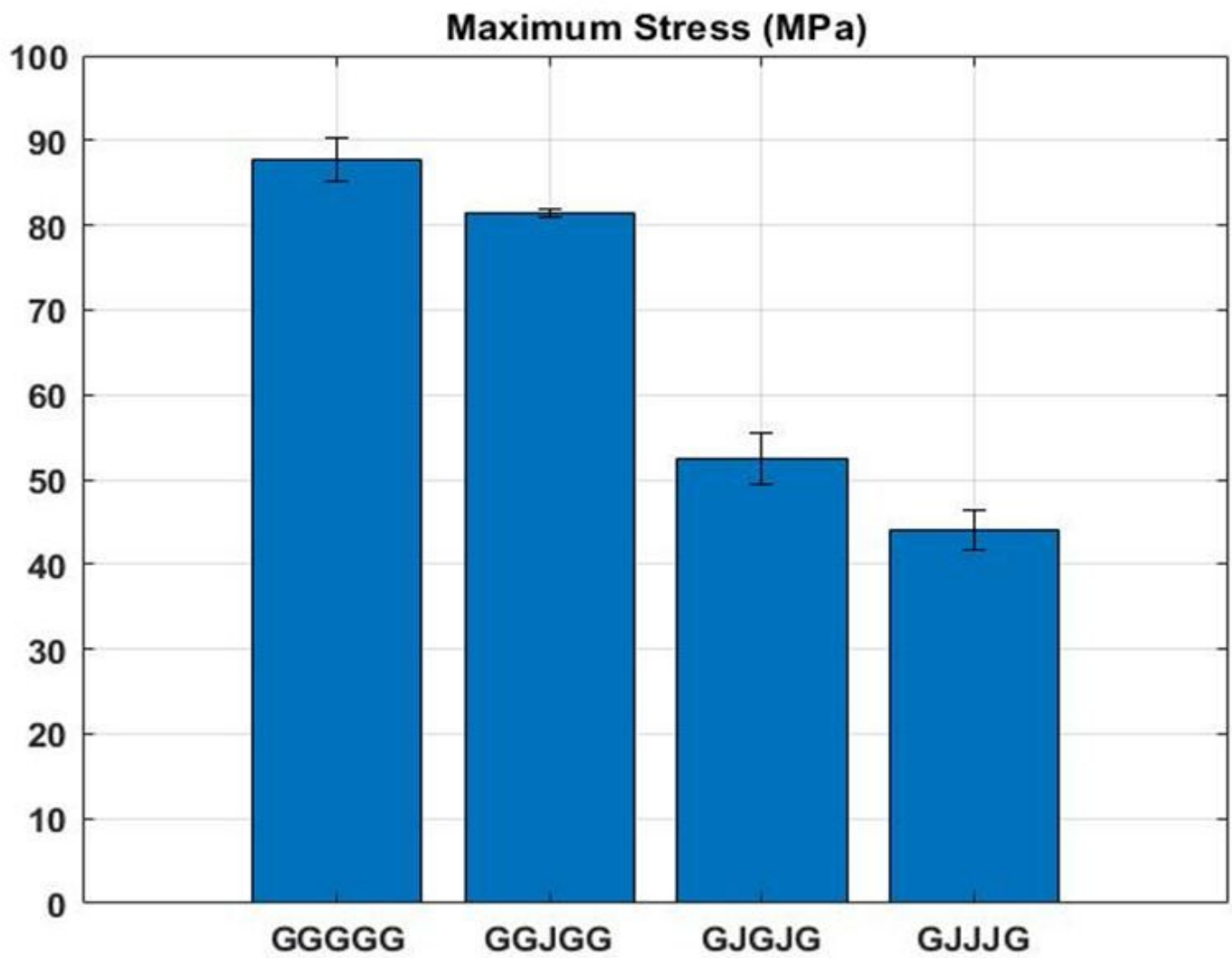


Figure 8

Bar chart of Maximum Tensile Strength

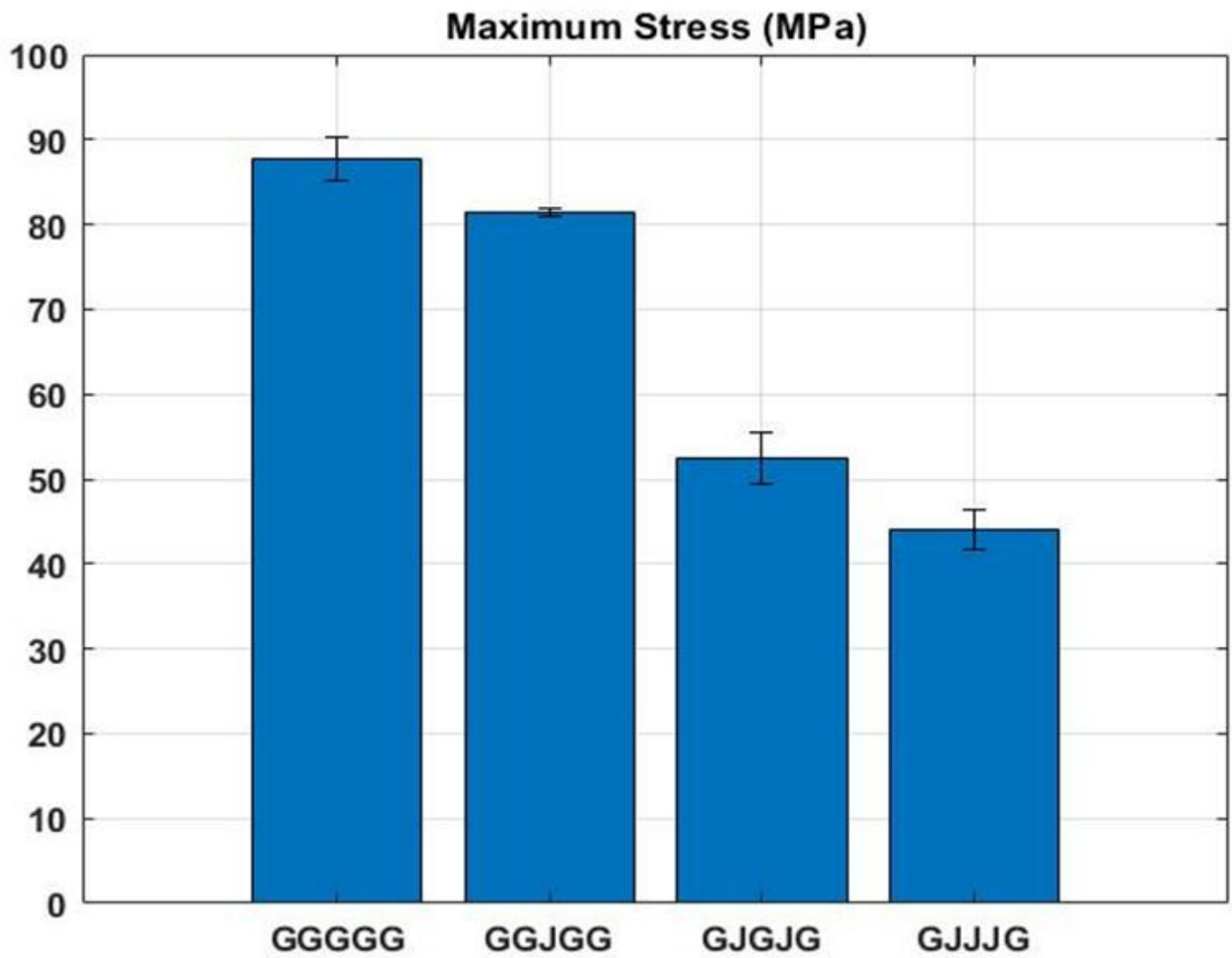


Figure 8

Bar chart of Maximum Tensile Strength

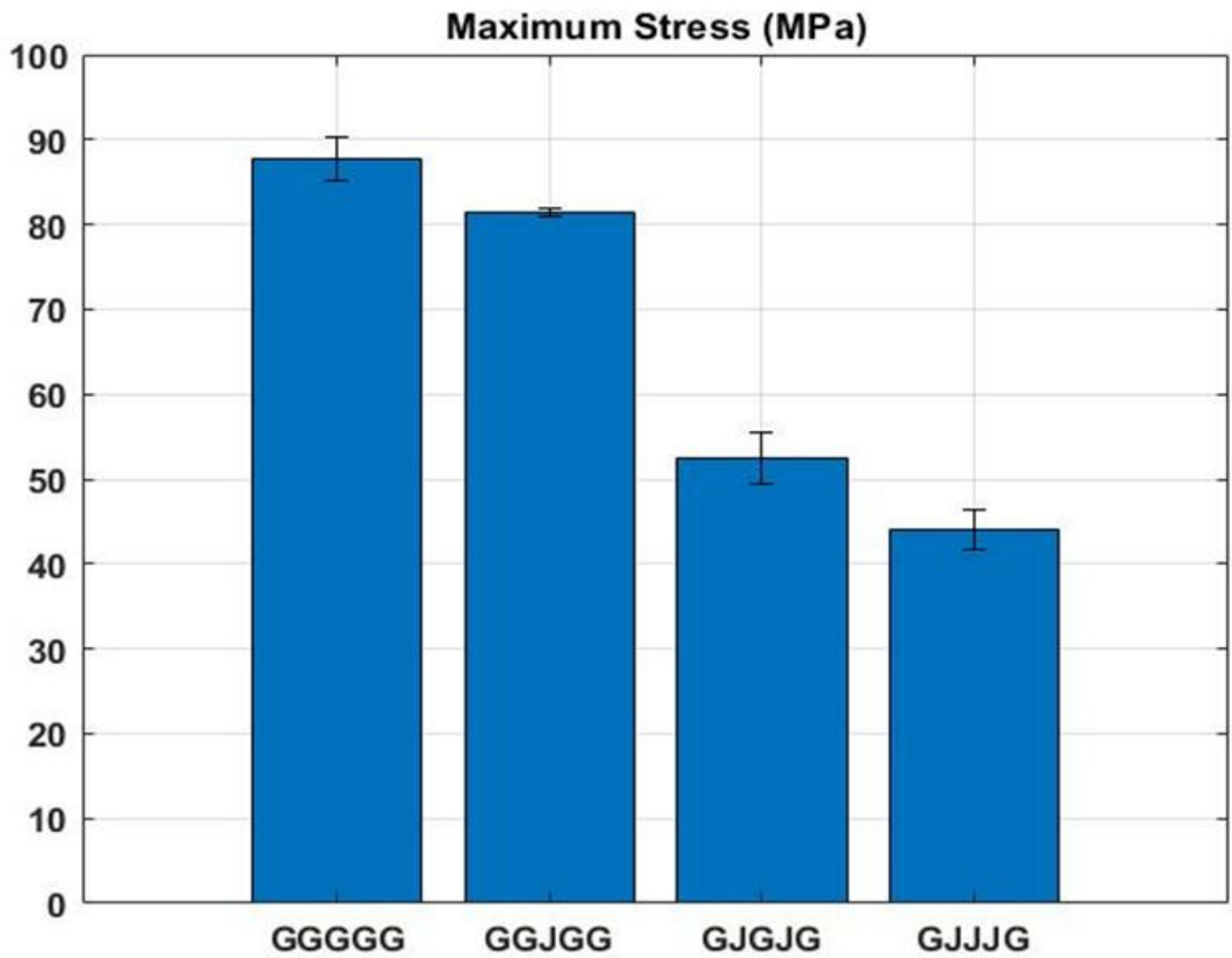


Figure 8

Bar chart of Maximum Tensile Strength

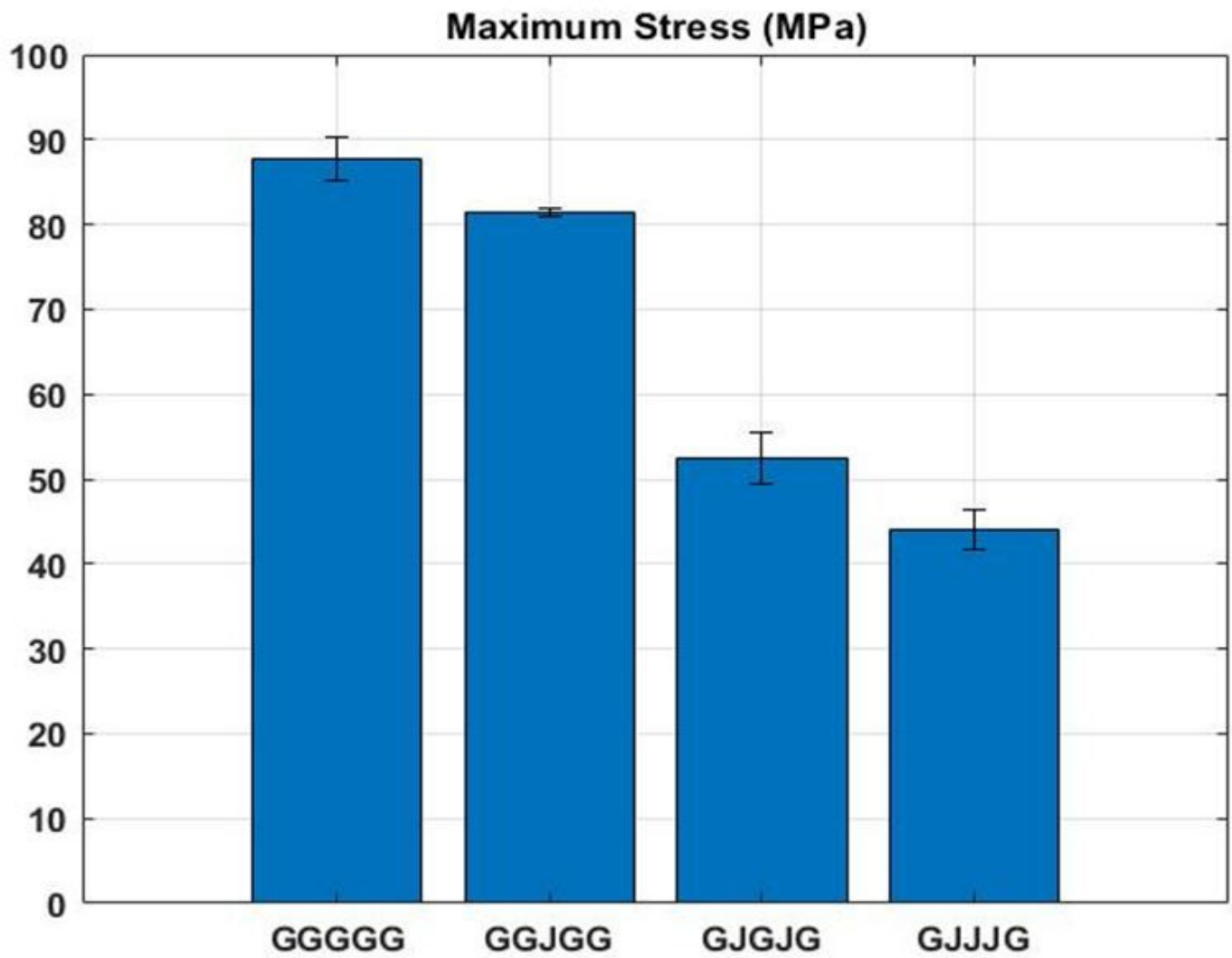


Figure 8

Bar chart of Maximum Tensile Strength

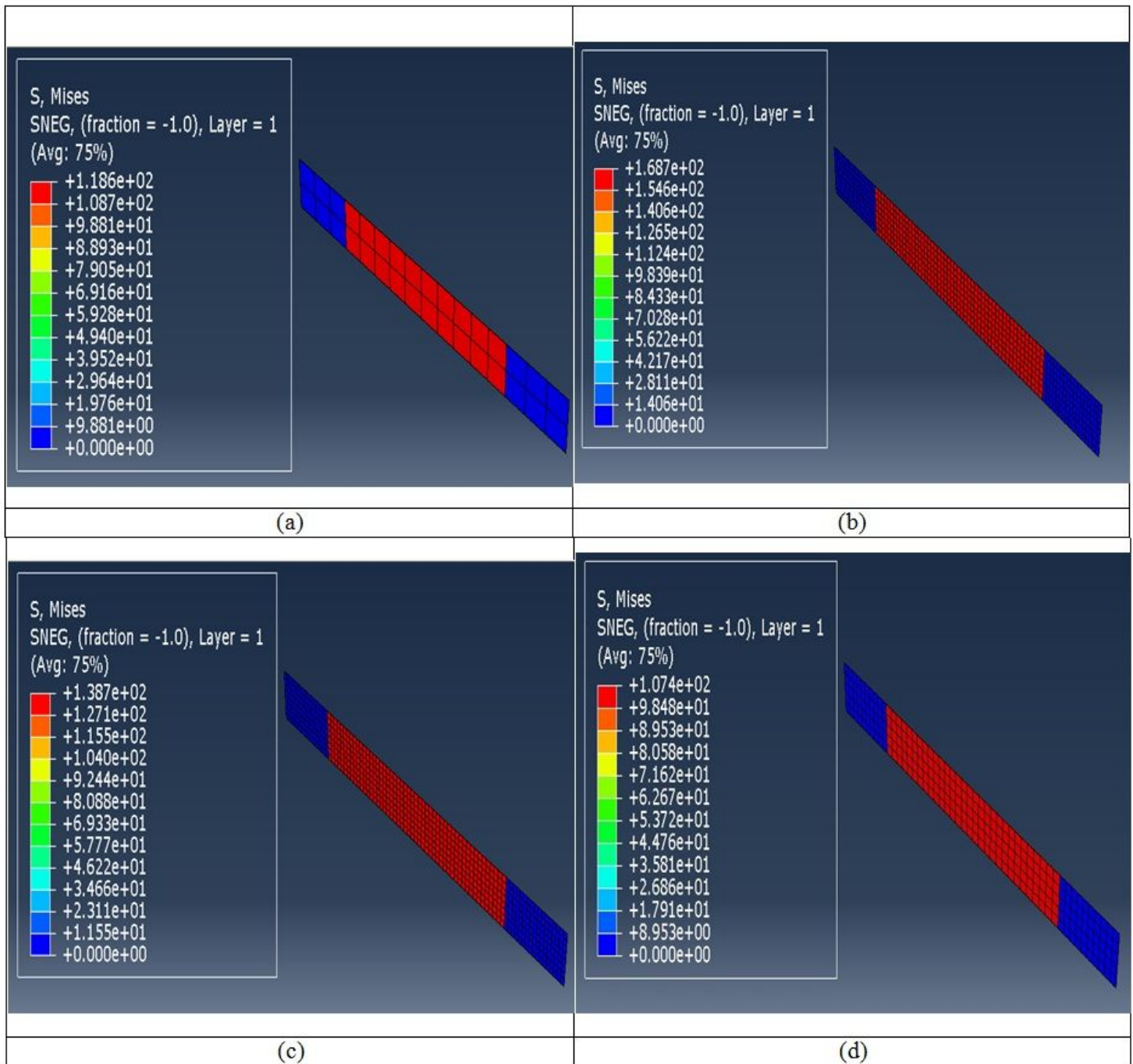


Figure 9

Contour plots for von-Mises stress (a) GGGGG (b) GGJGG (c) GJGJG (d) GJJJG

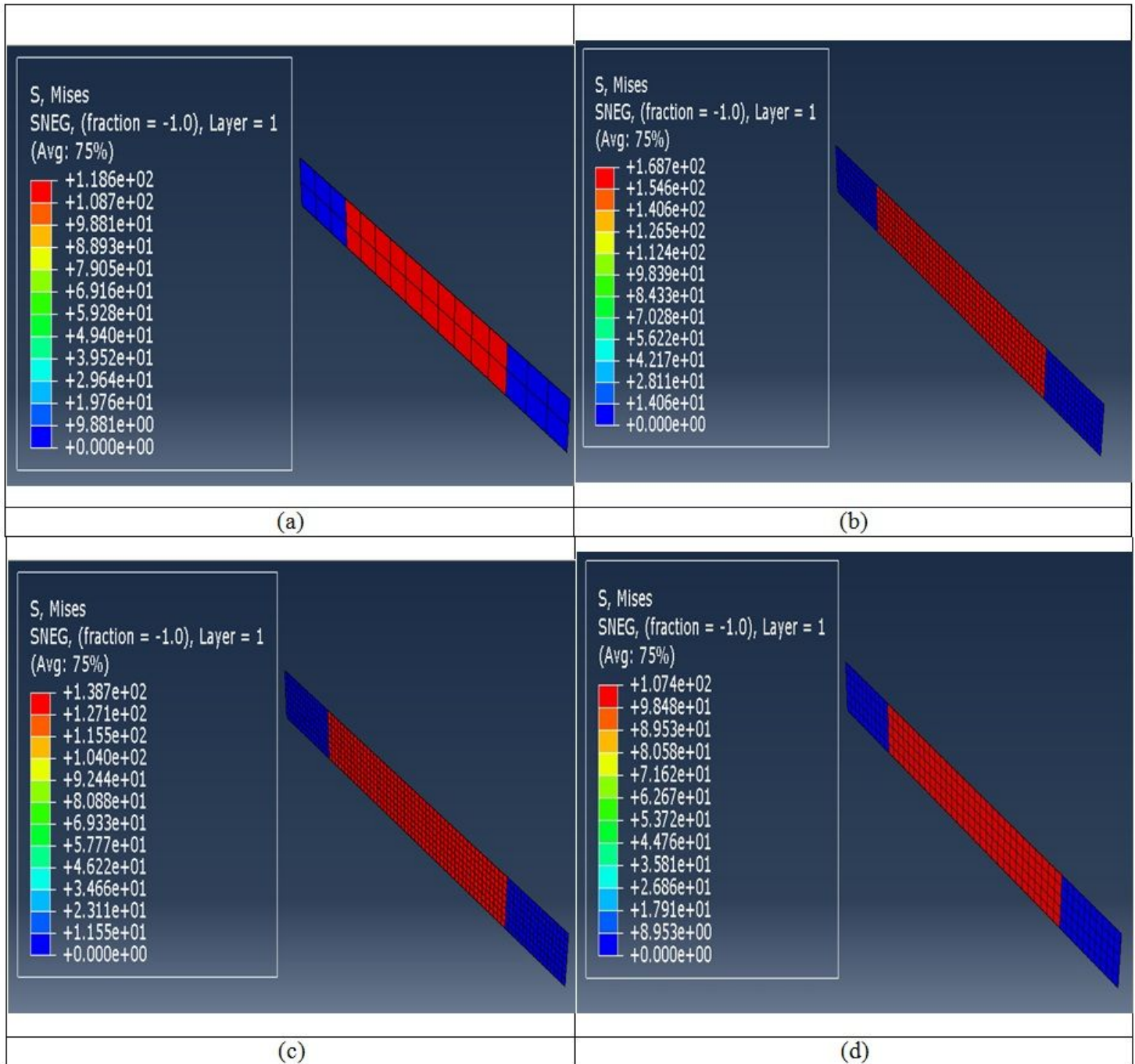


Figure 9

Contour plots for von-Mises stress (a) GGGGG (b) GGJGG (c) GJGJG (d) GJJJG

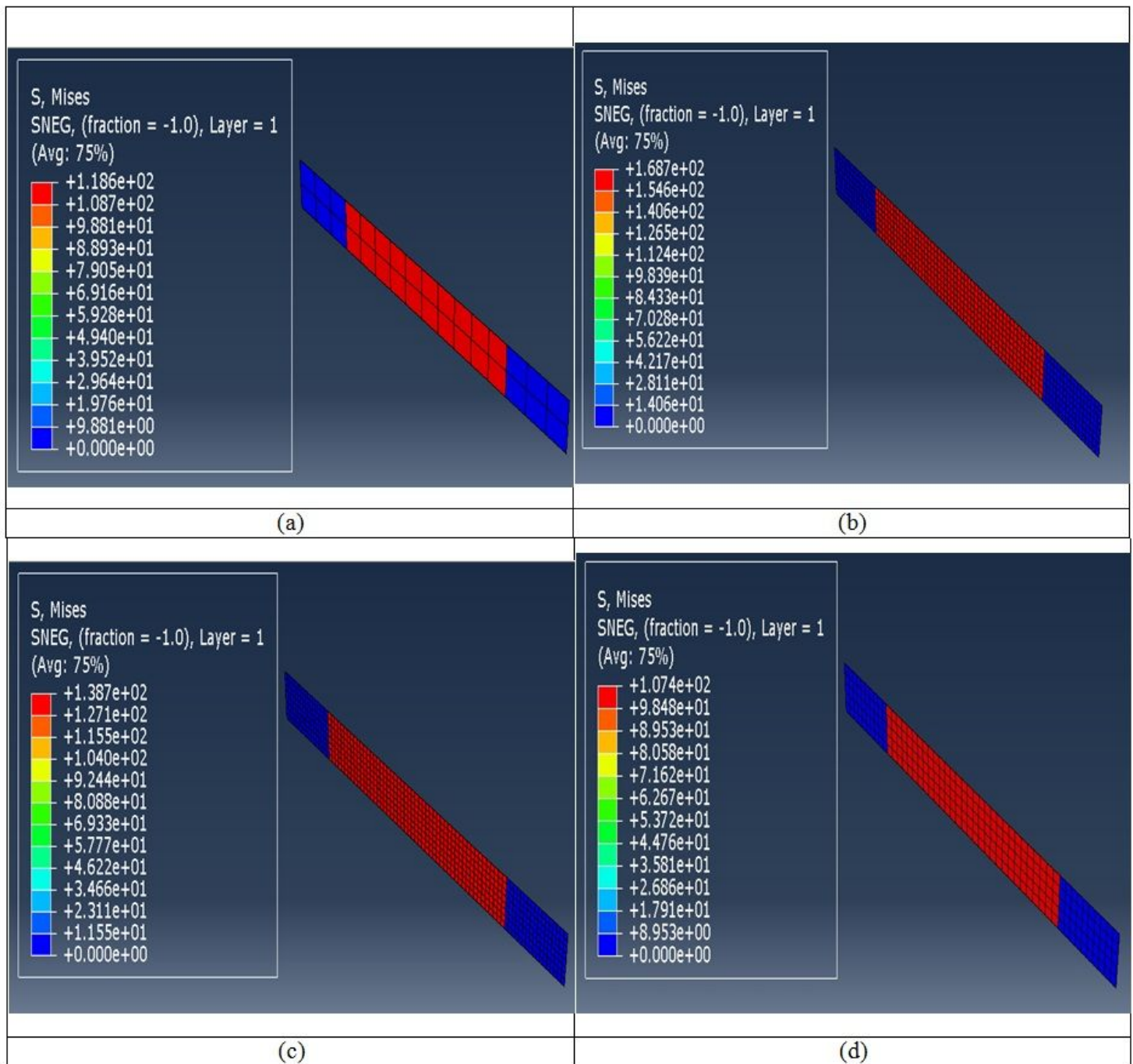


Figure 9

Contour plots for von-Mises stress (a) GGGGG (b) GGJGG (c) GJGJG (d) GJJJG

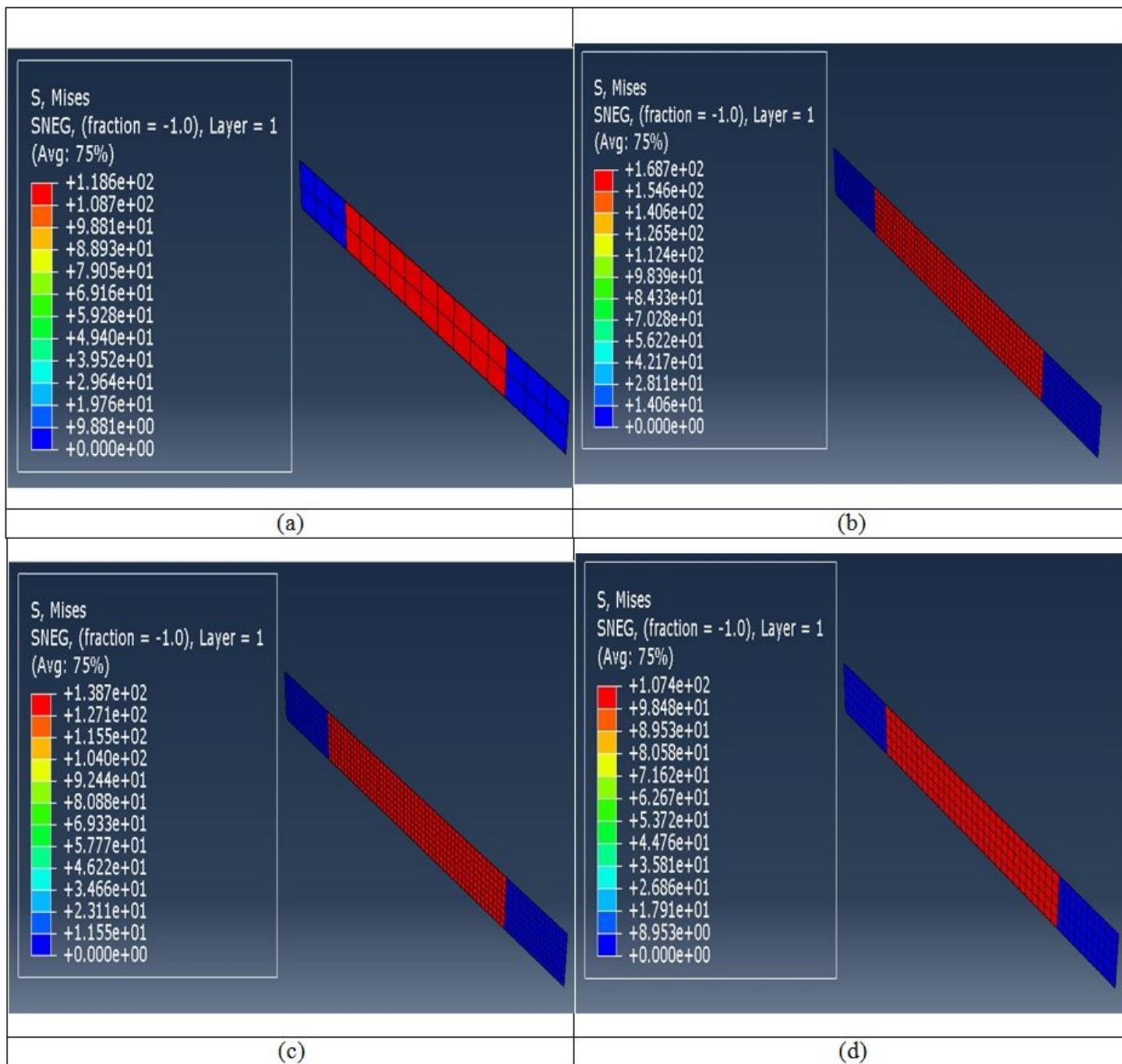


Figure 9

Contour plots for von-Mises stress (a) GGGGG (b) GGJGG (c) GJGJG (d) GJJJG

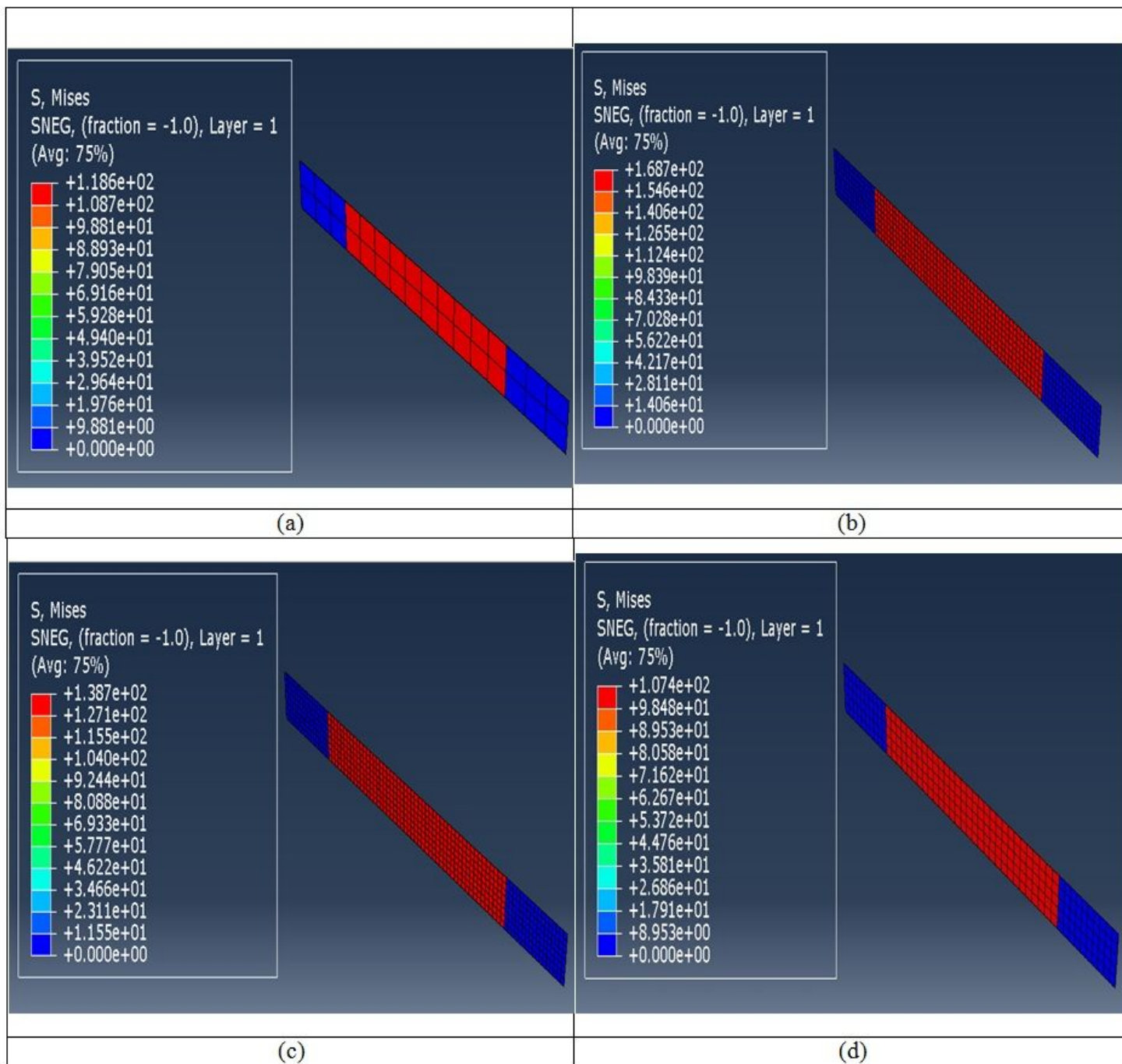


Figure 9

Contour plots for von-Mises stress (a) GGGGG (b) GGJGG (c) GJGJG (d) GJJJG

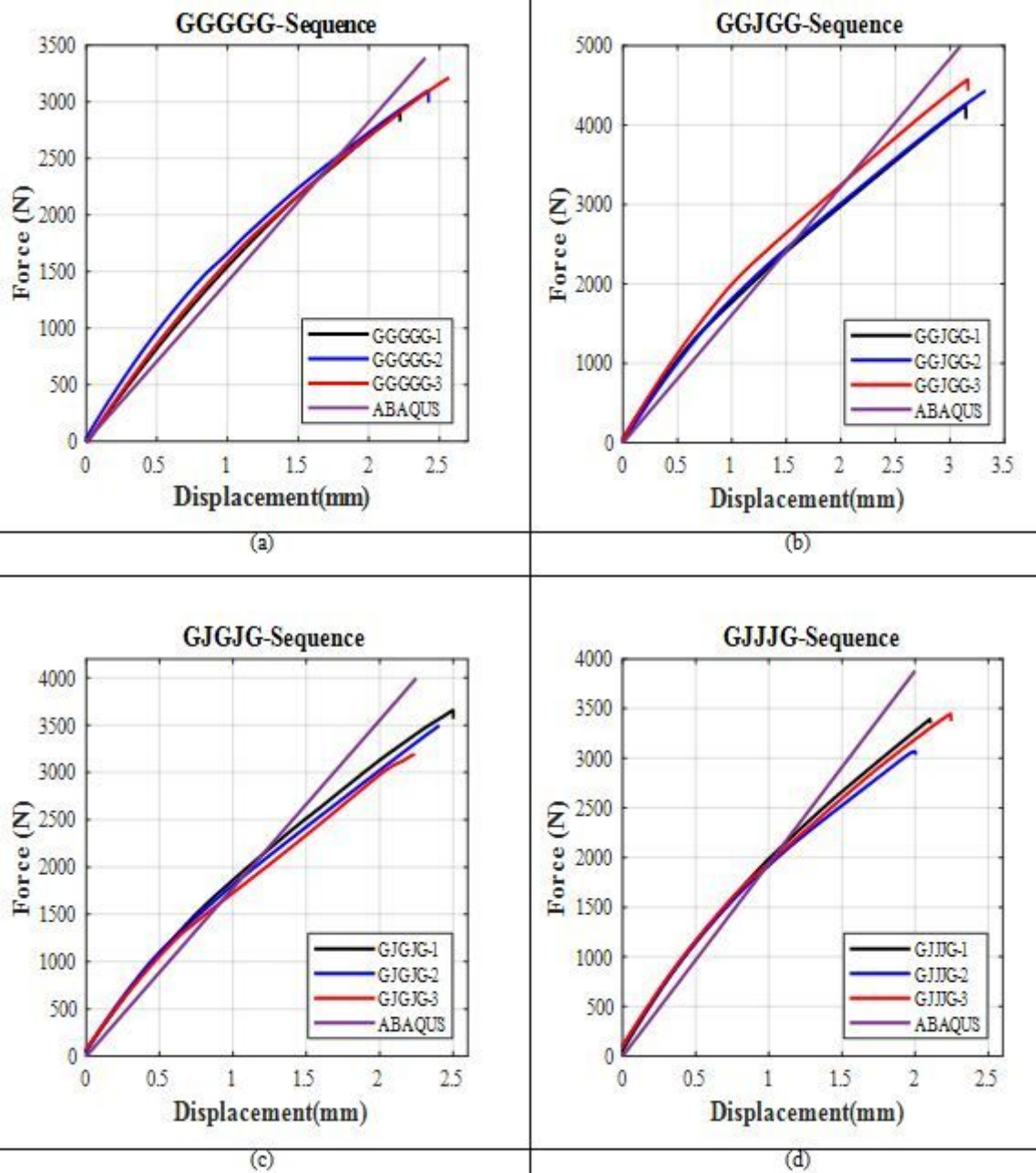
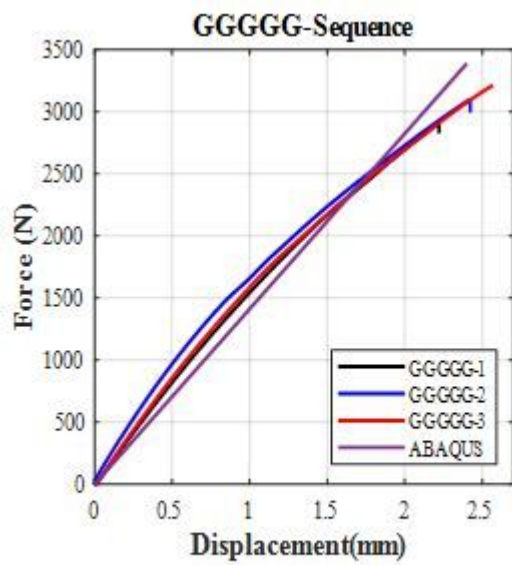
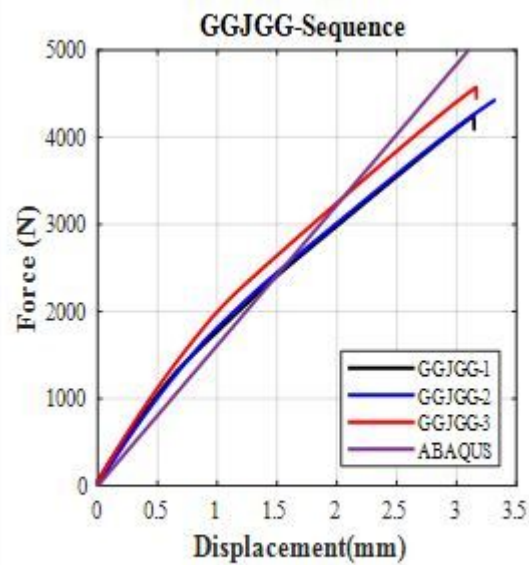


Figure 10

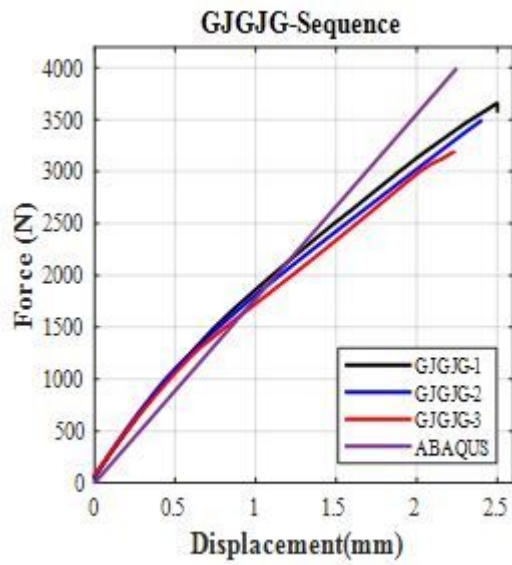
(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence



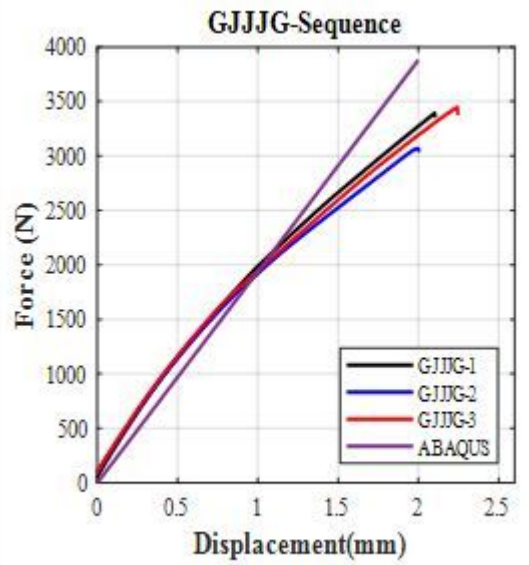
(a)



(b)



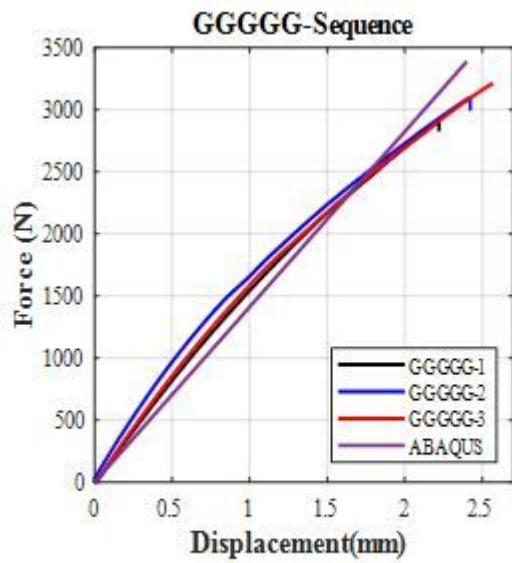
(c)



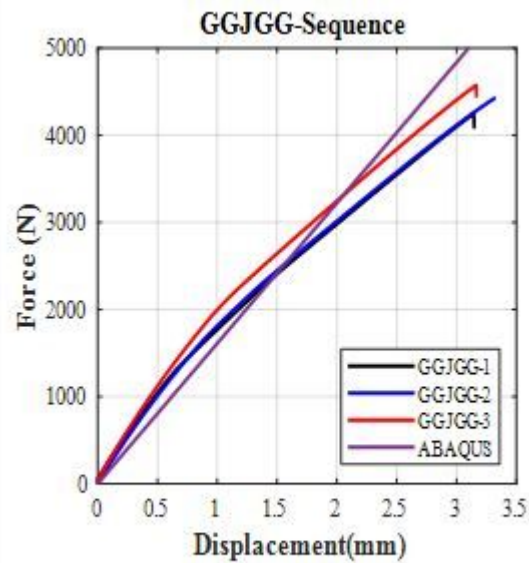
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Figure 10

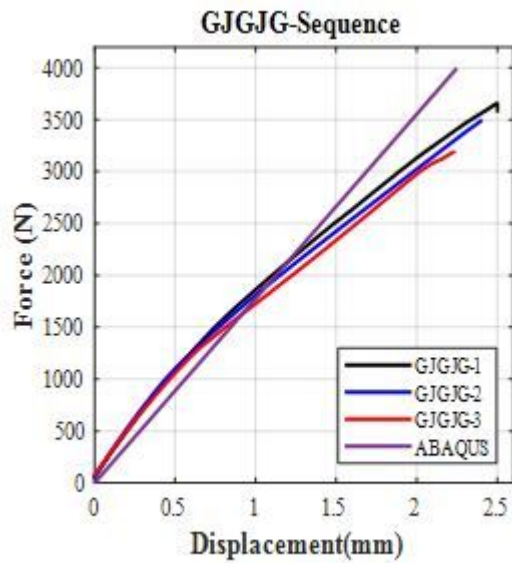
(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence



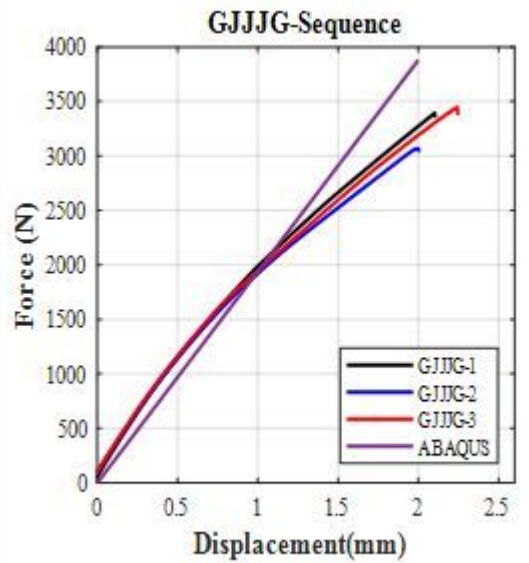
(a)



(b)



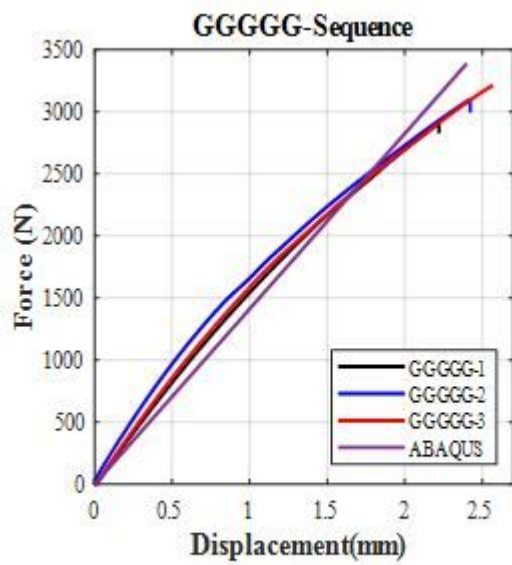
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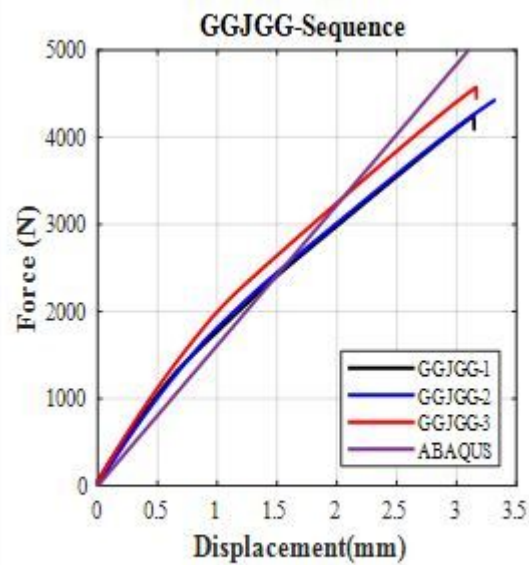
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Figure 10

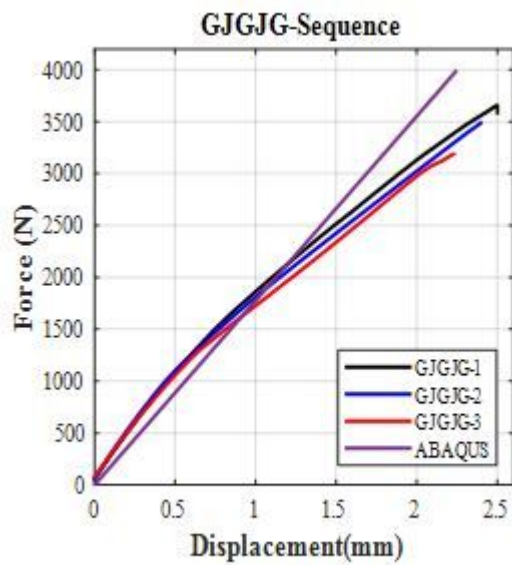
(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence



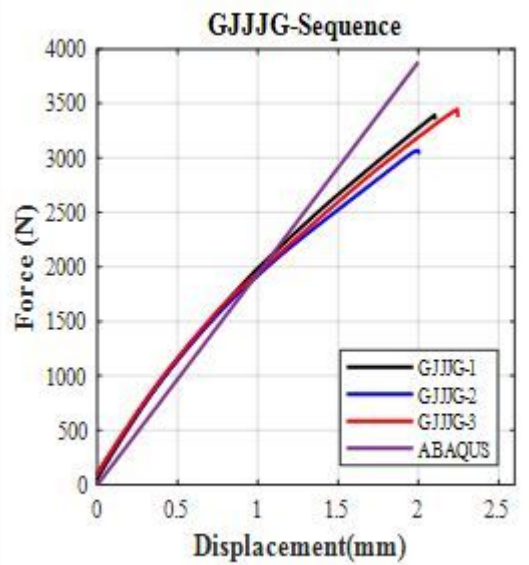
(a)



(b)



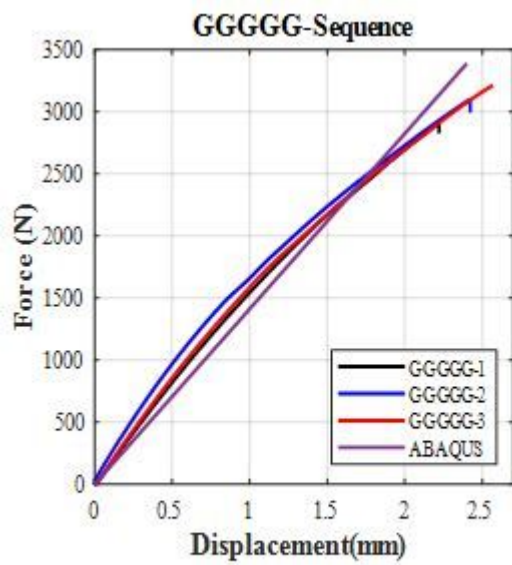
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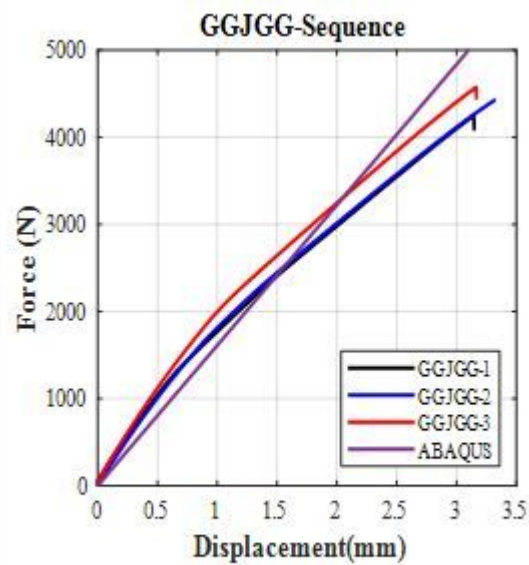
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Figure 10

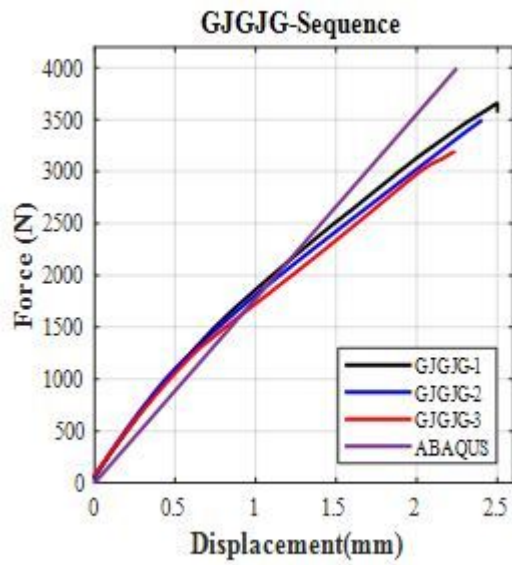
(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence



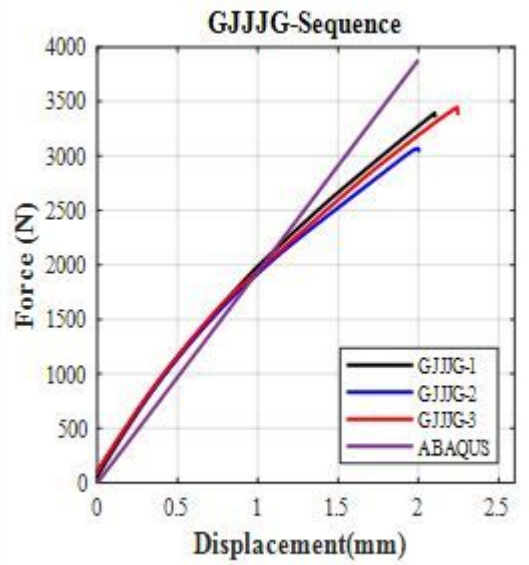
(a)



(b)



(c)



(d)

Figure 10

(a) Graphs of GGGG sequence (b) Graphs of GGJGG sequence (c) Graphs of GJGJG sequence (d) Graphs of GJJJG sequence

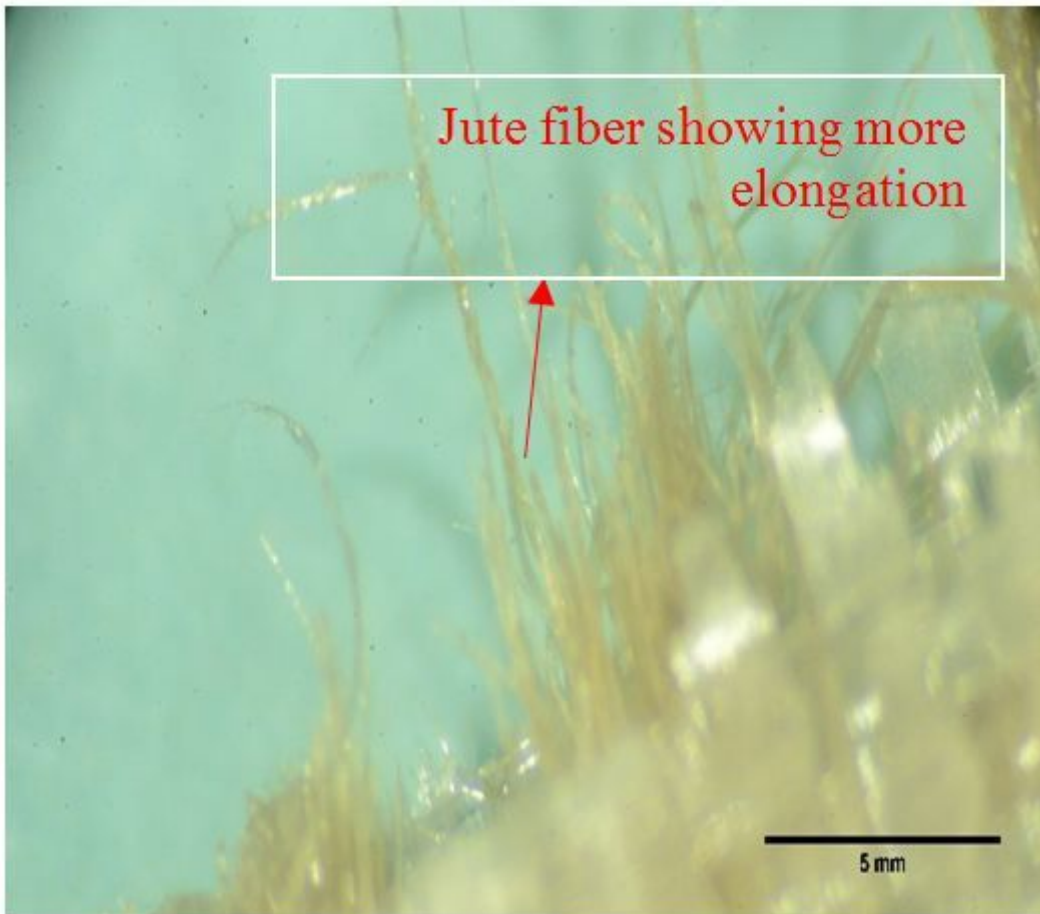


Figure 11

Top View

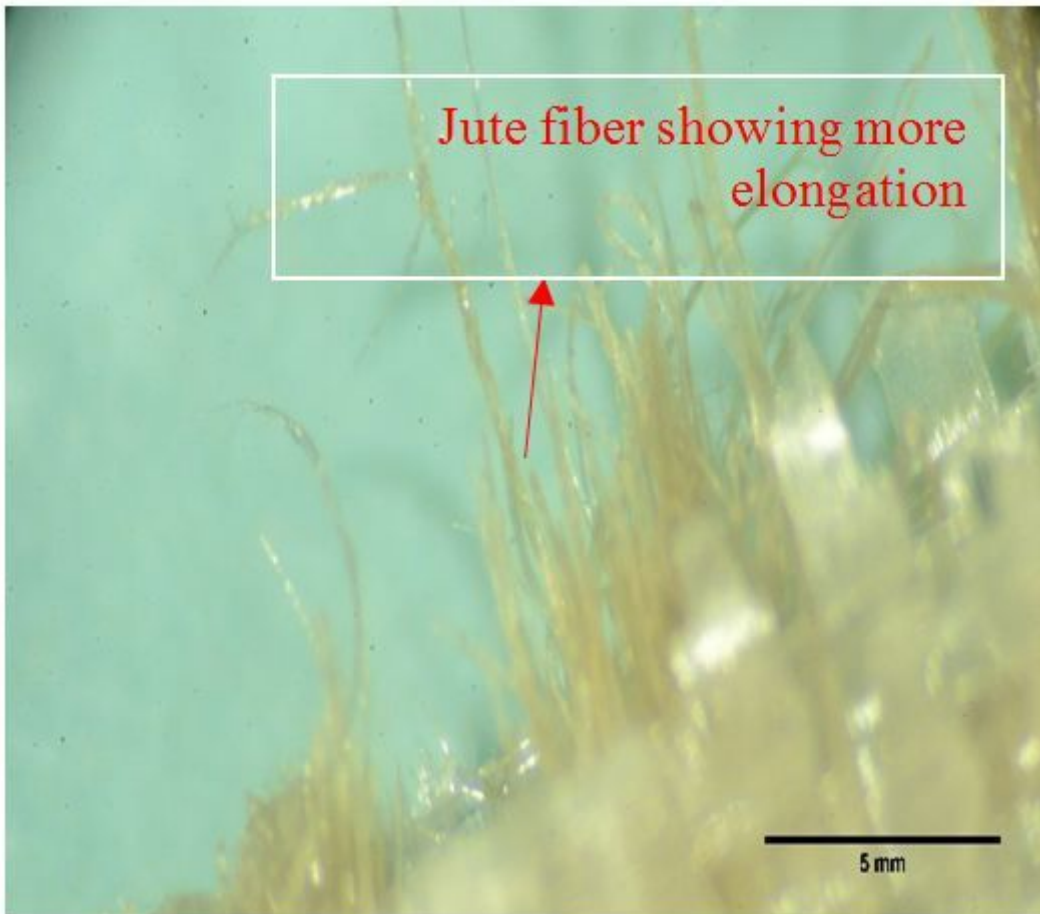


Figure 11

Top View

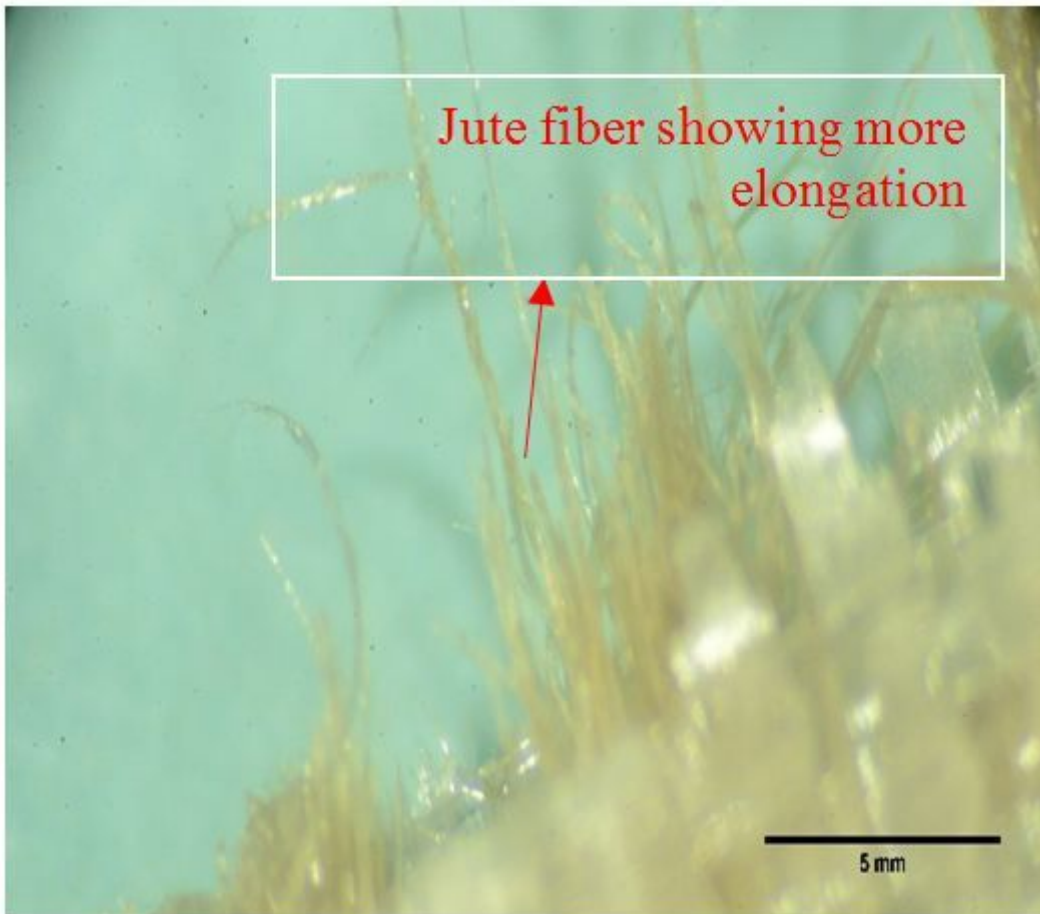


Figure 11

Top View

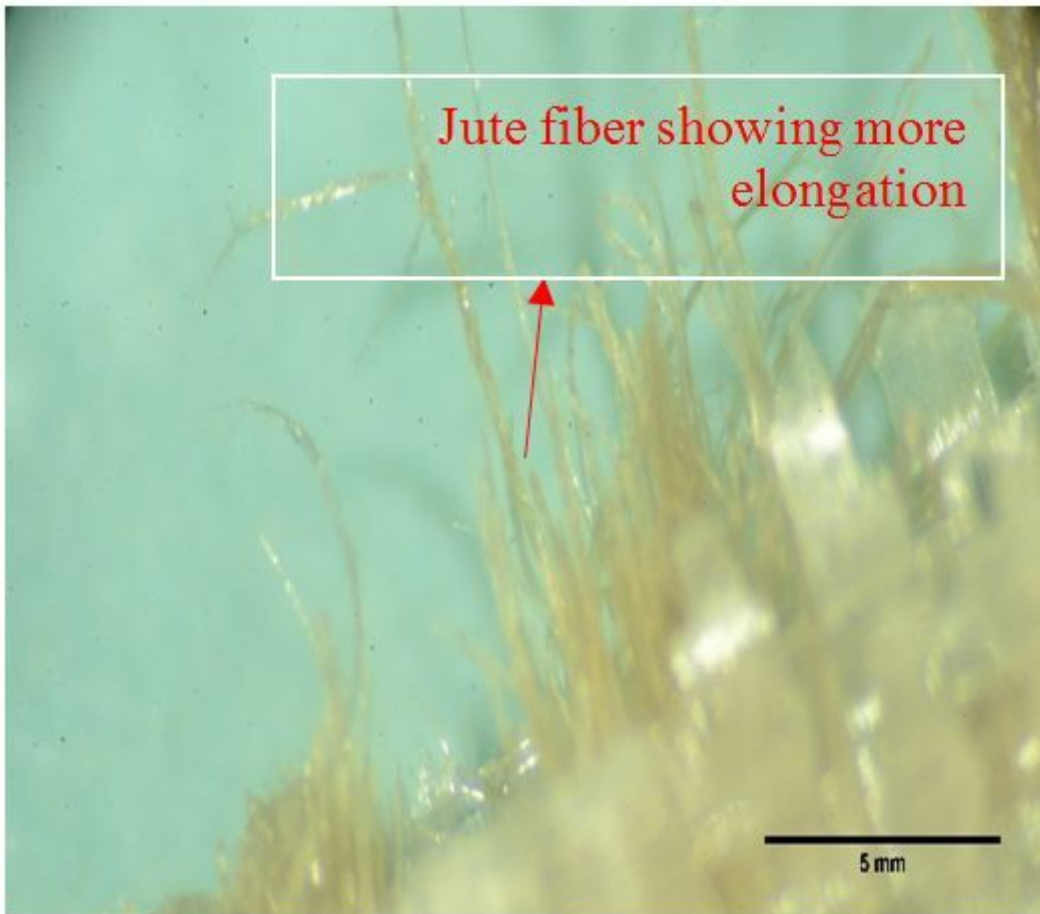


Figure 11

Top View

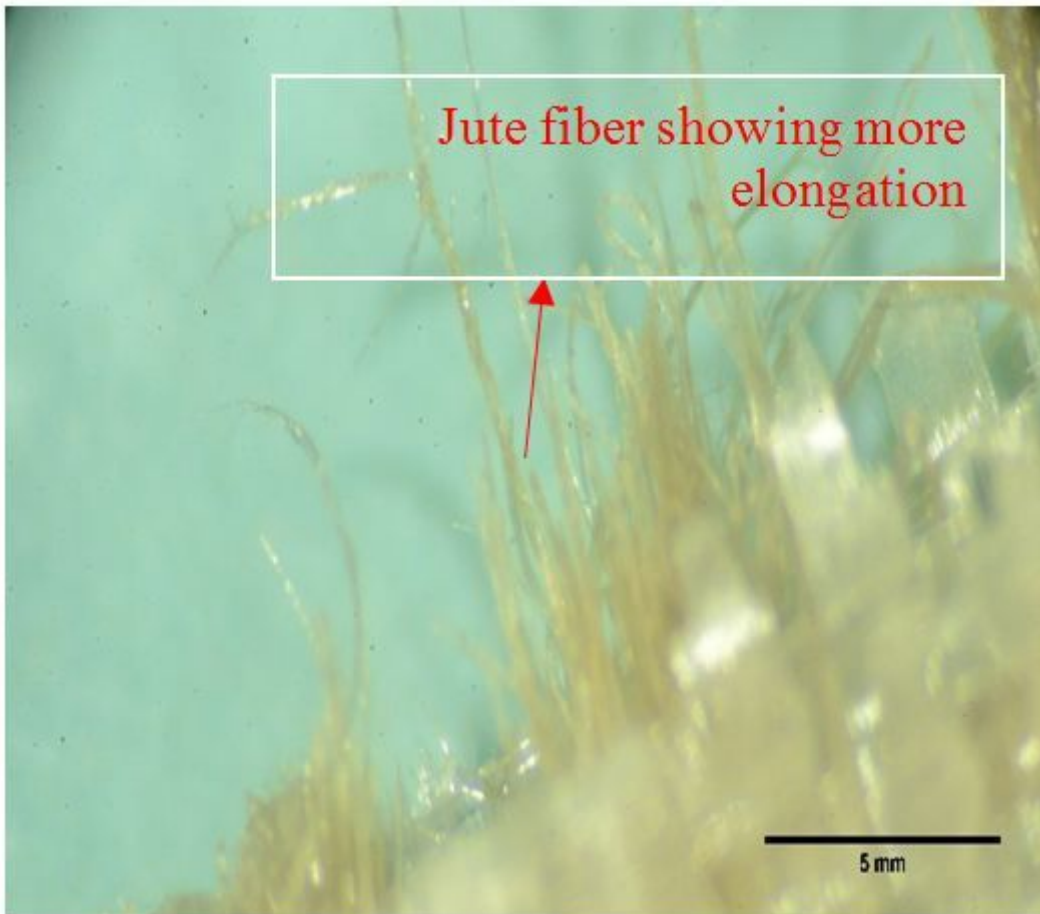


Figure 11

Top View

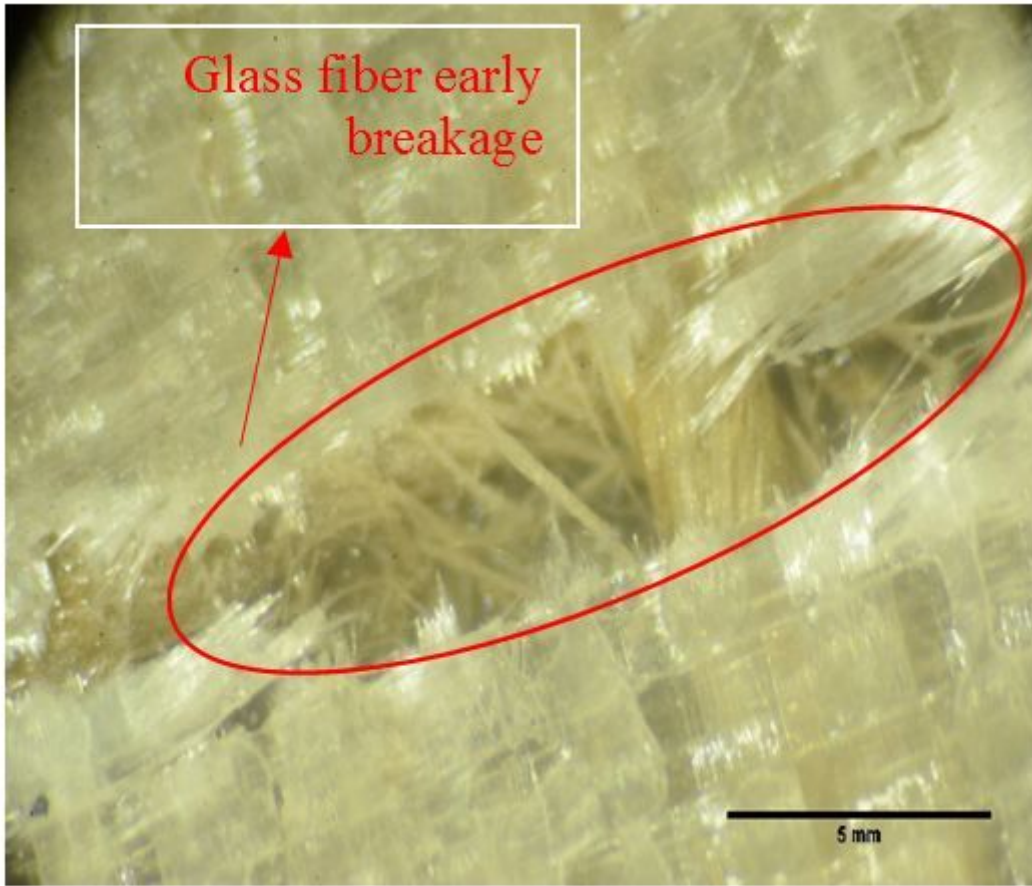


Figure 12

Glass fiber early breakage

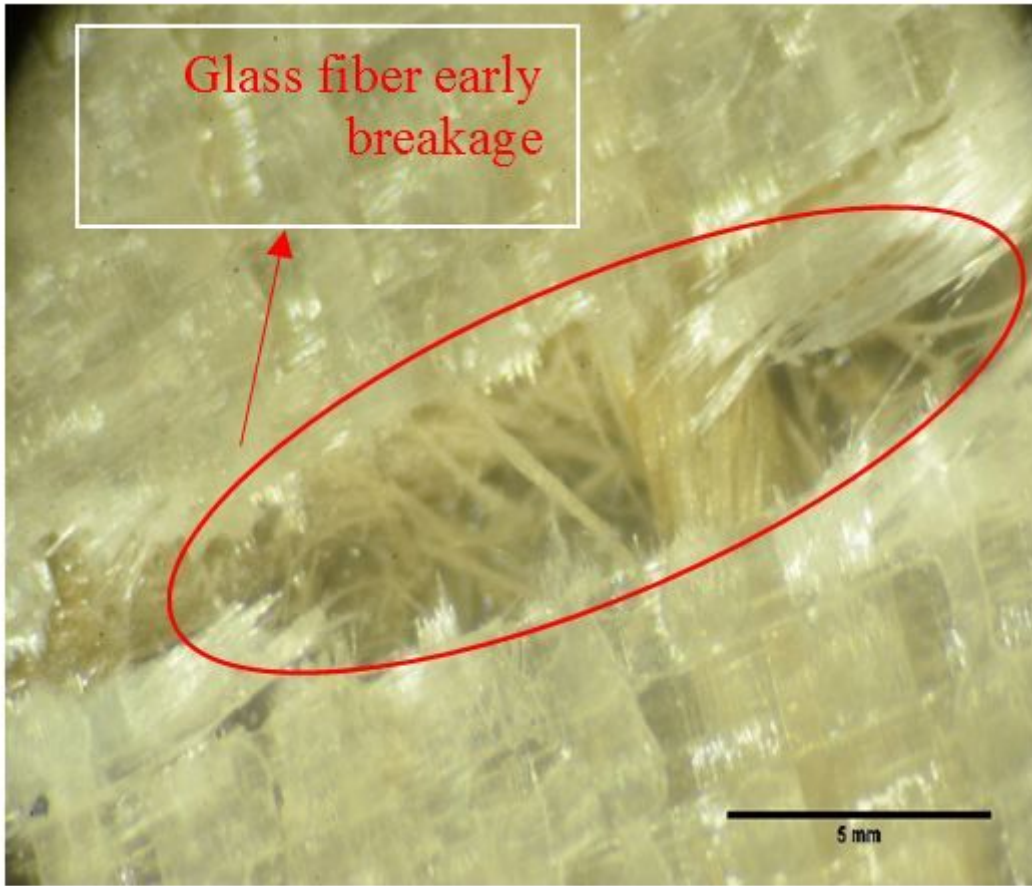


Figure 12

Glass fiber early breakage

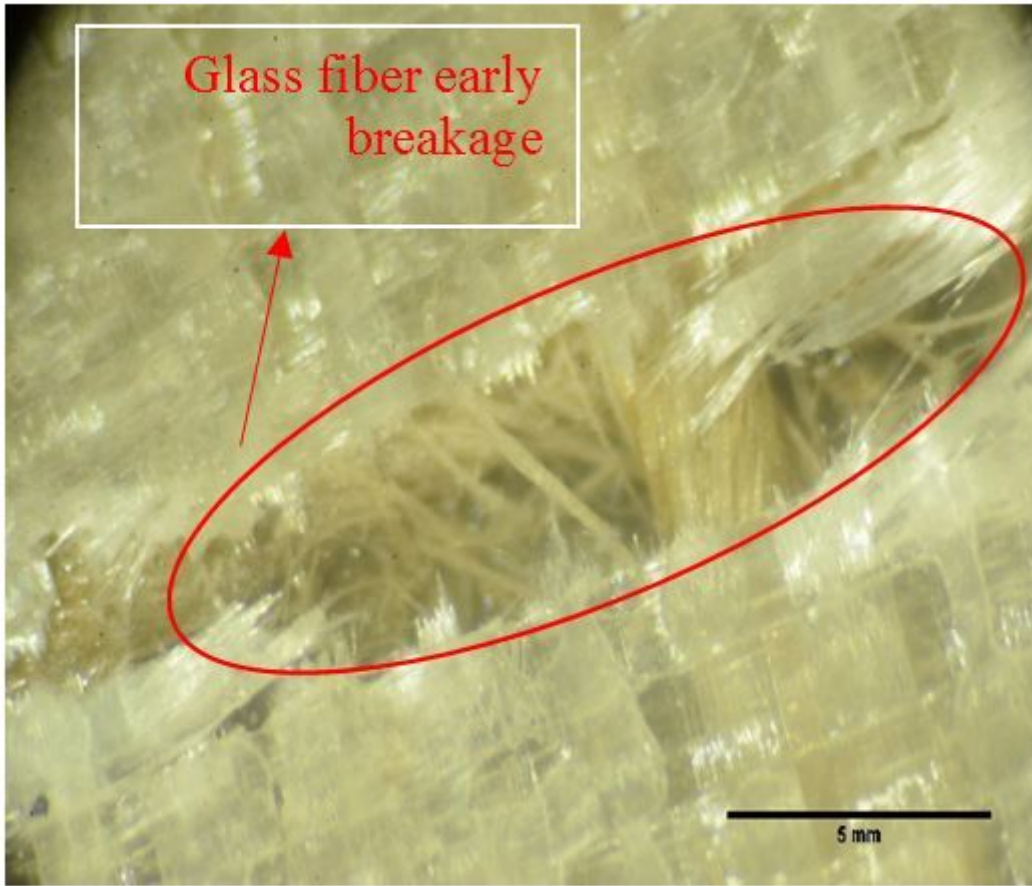


Figure 12

Glass fiber early breakage

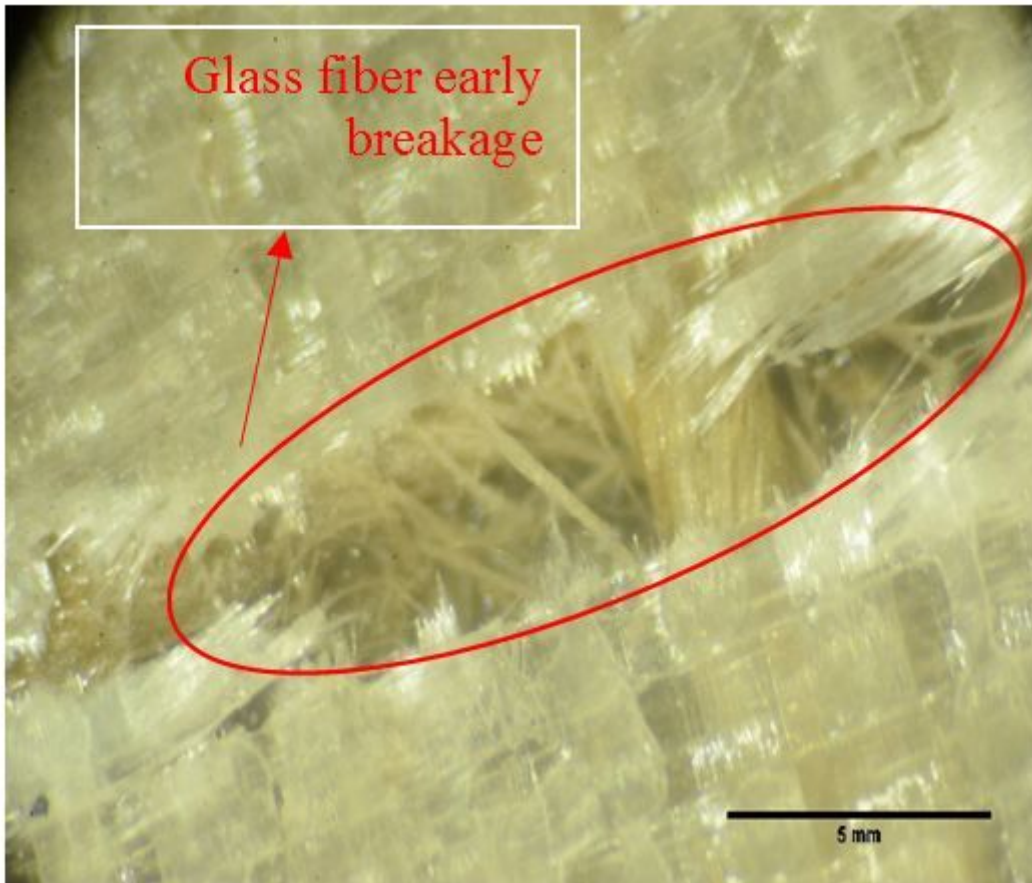


Figure 12

Glass fiber early breakage

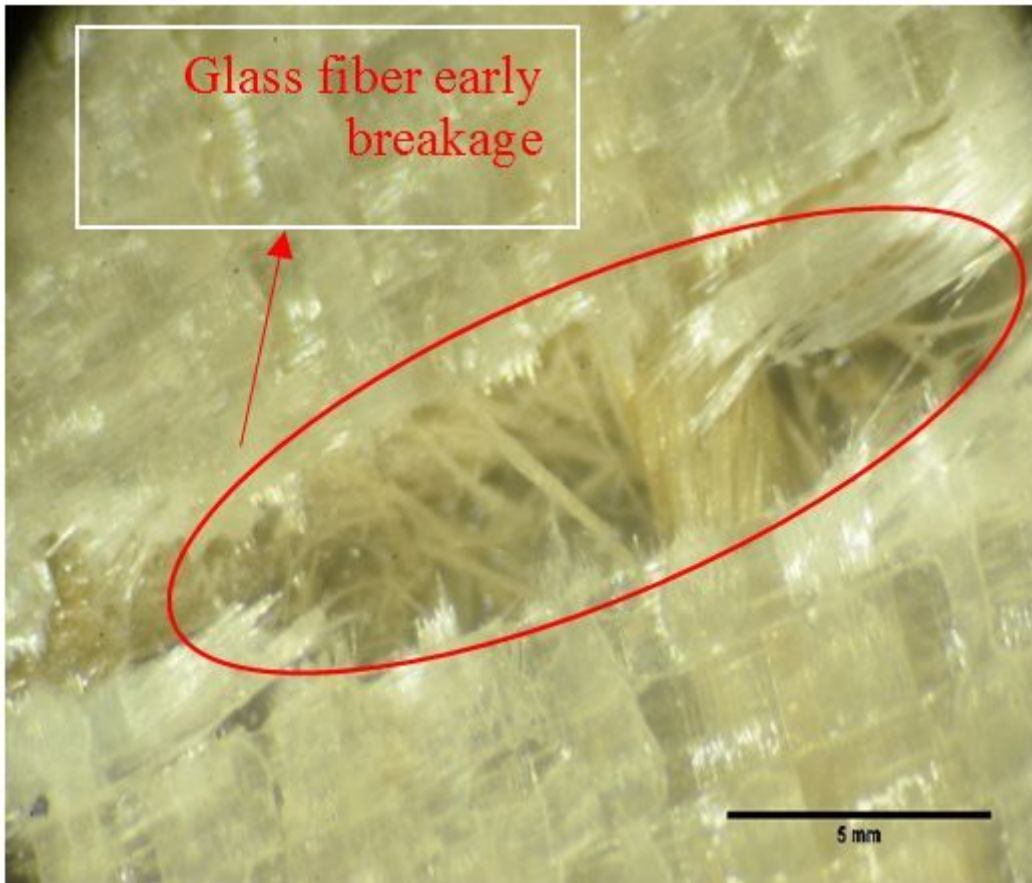


Figure 12

Glass fiber early breakage

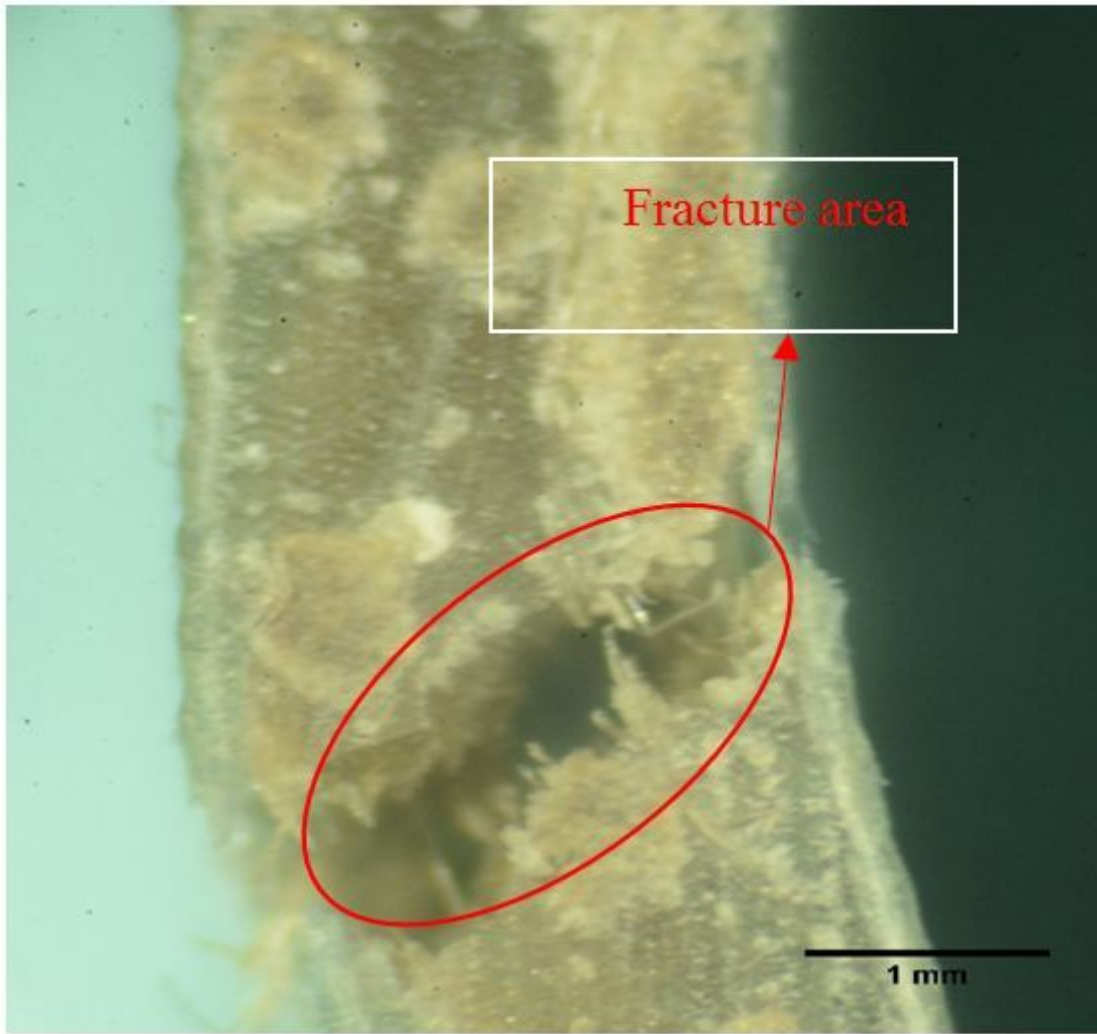


Figure 13

Side view of fractured specimens

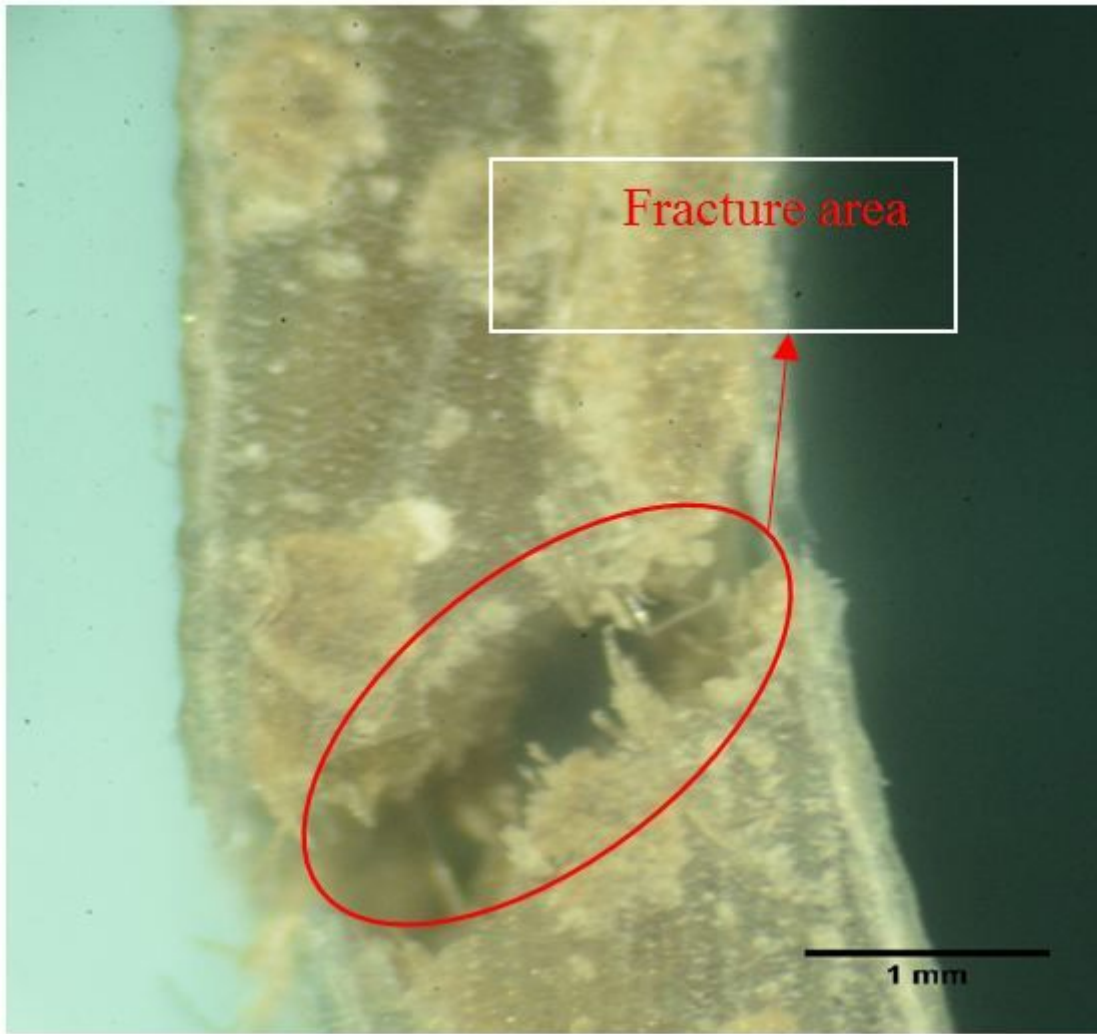


Figure 13

Side view of fractured specimens

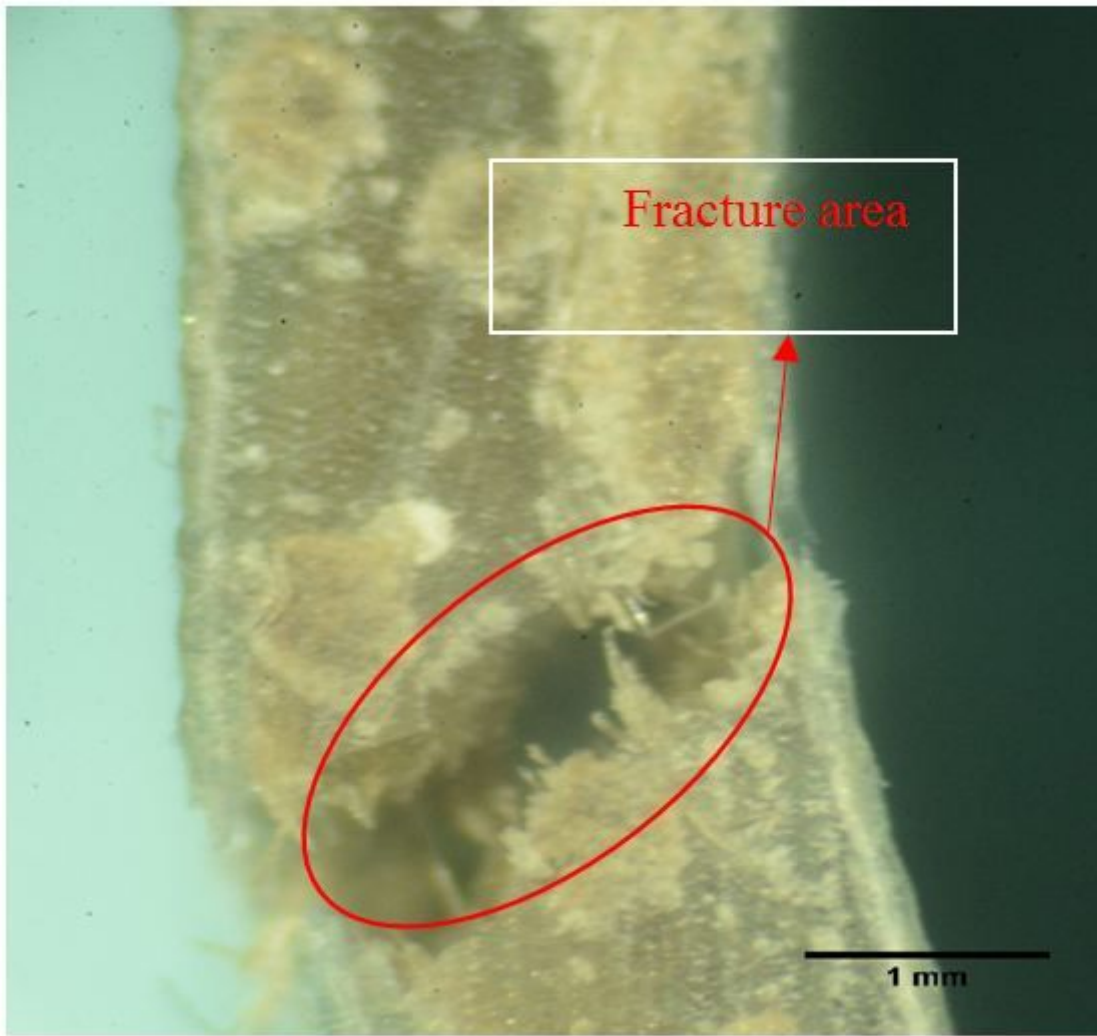


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Side view of fractured specimens

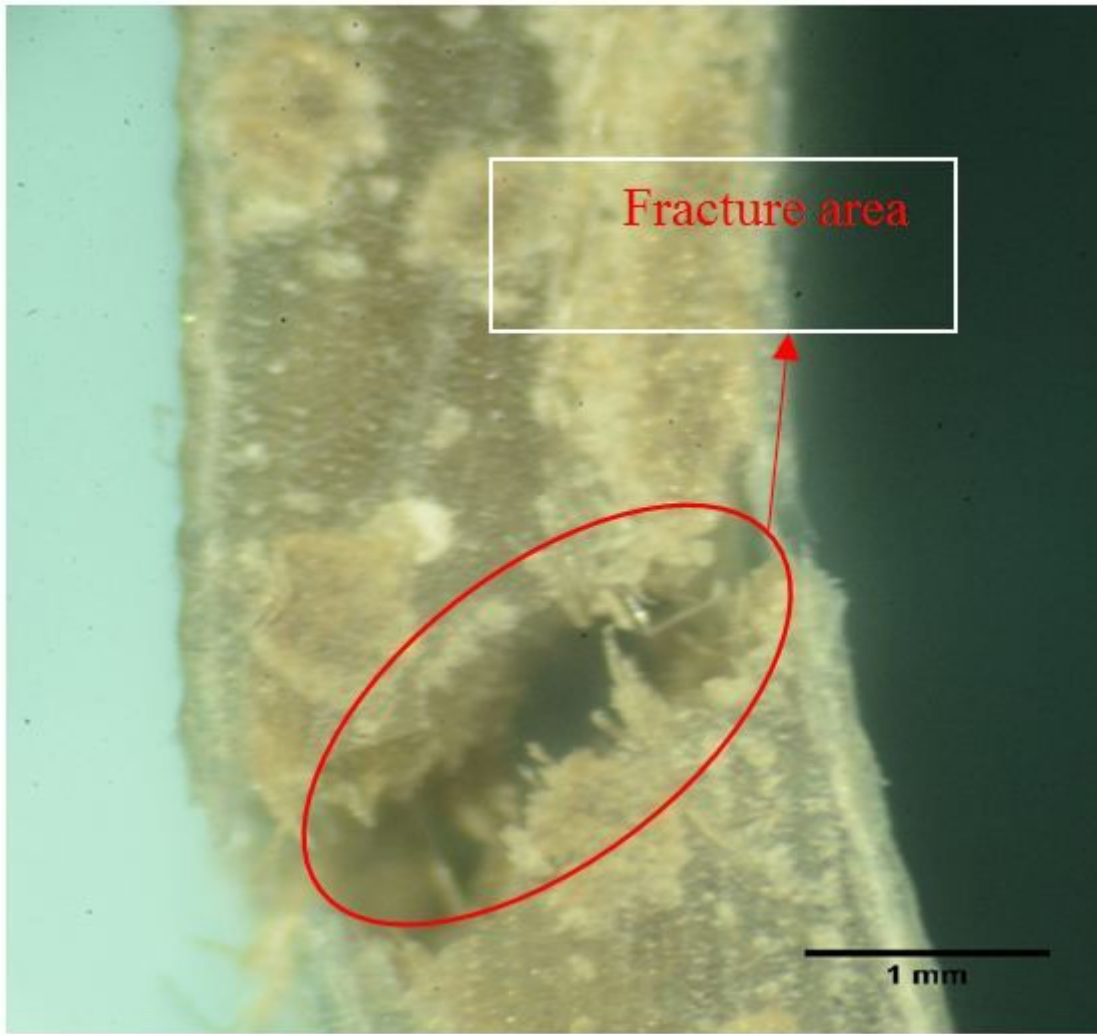


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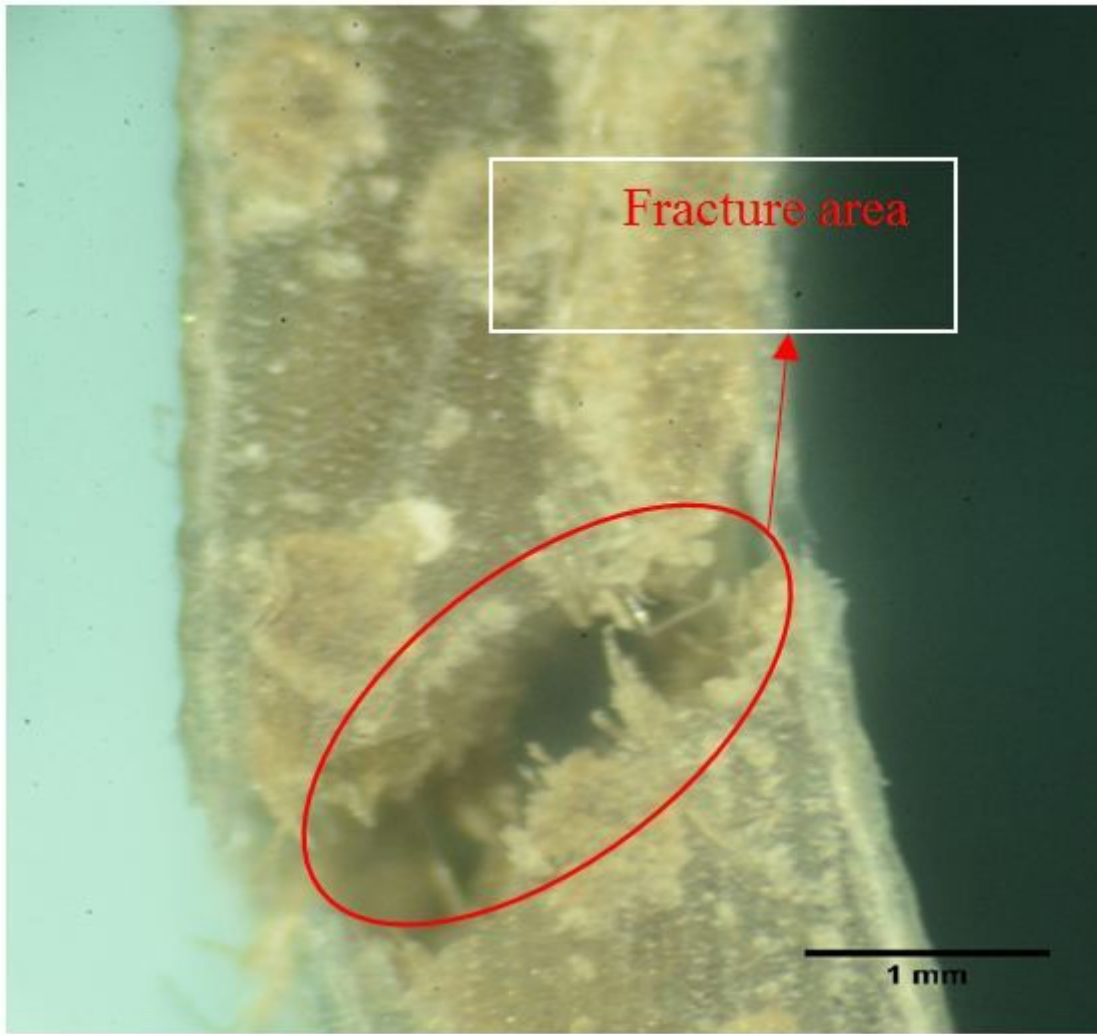


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Side view of fractured specimens

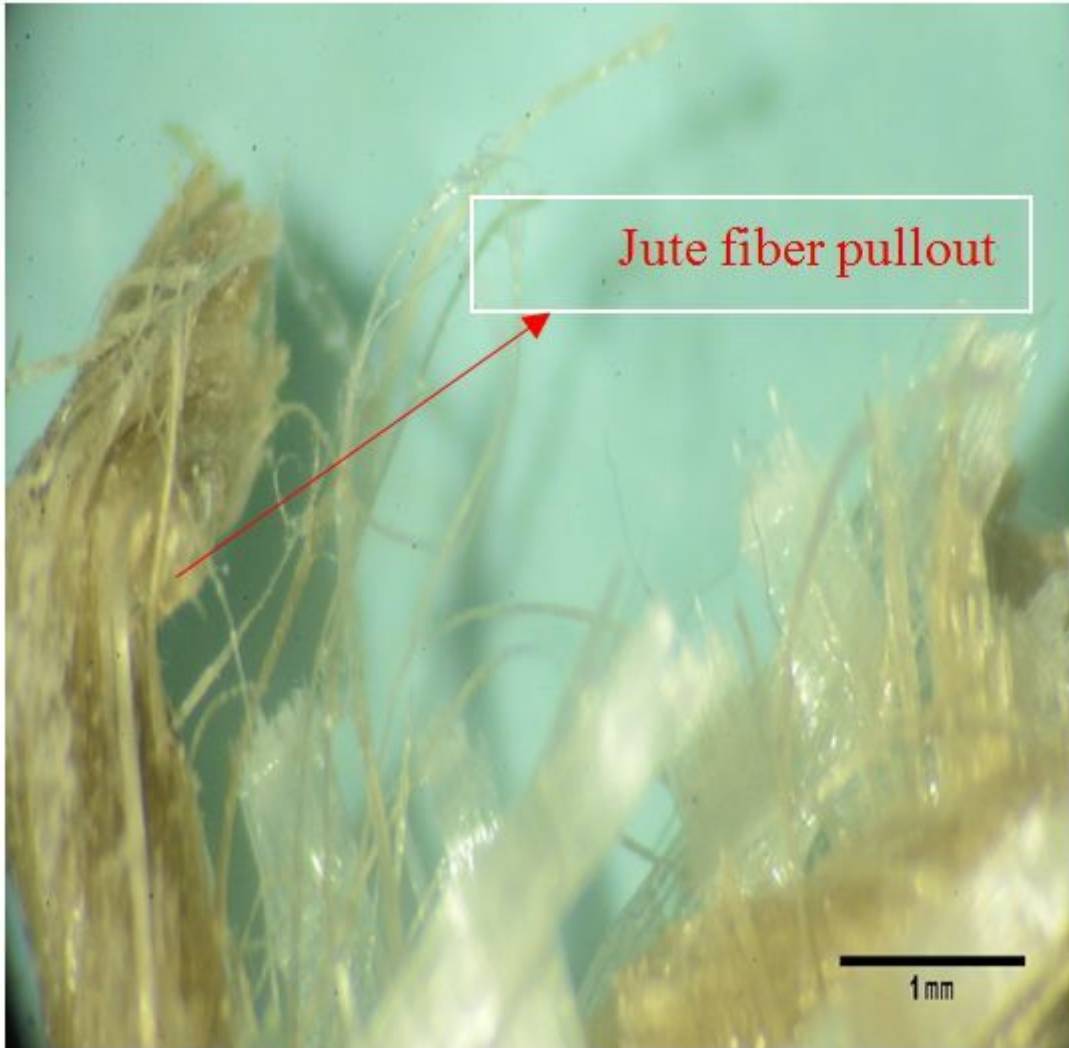


Figure 14

Jute fiber pullout

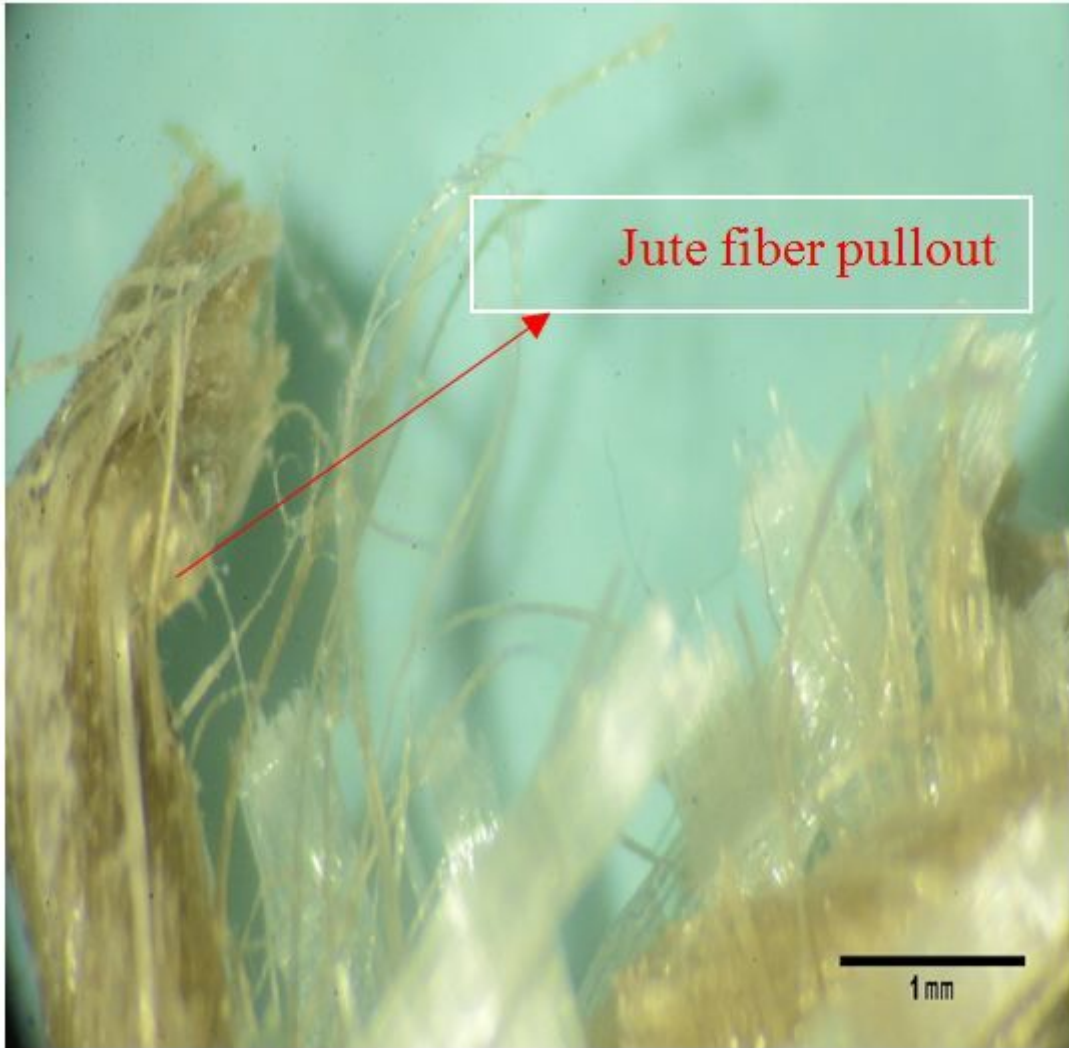


Figure 14

Jute fiber pullout

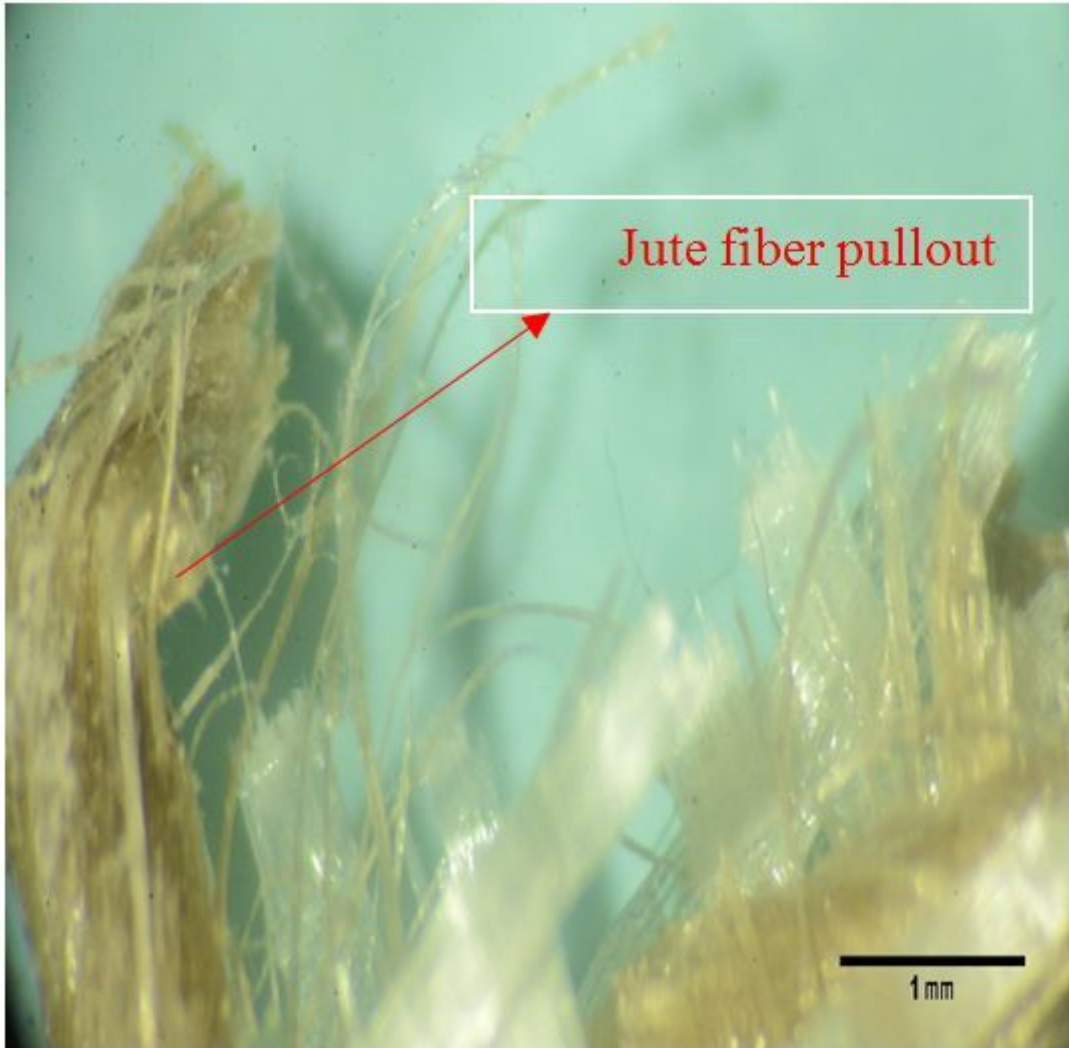


Figure 14

Jute fiber pullout

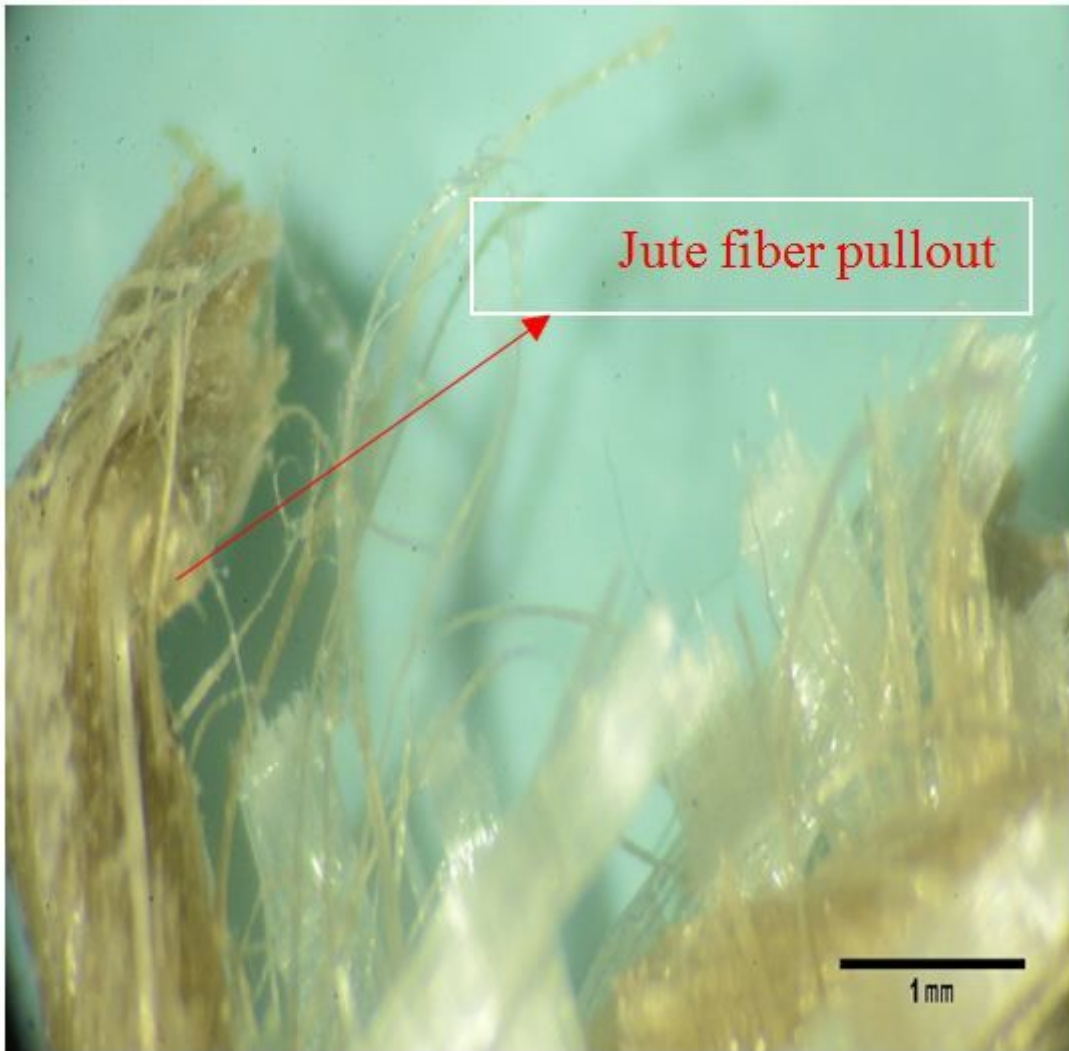


Figure 14

Jute fiber pullout

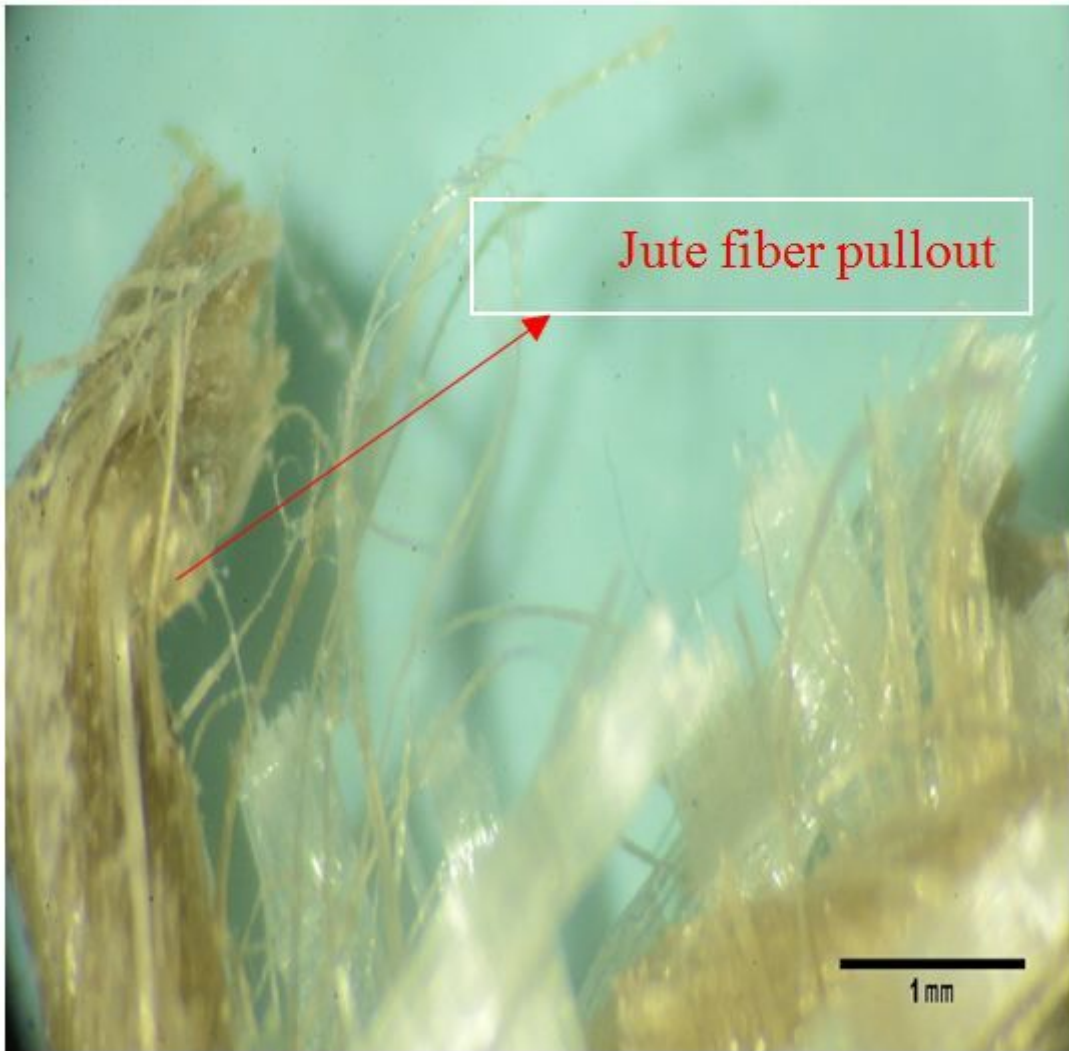


Figure 14

Jute fiber pullout