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Loading Rate Sensitivity of Jute/Glass Hybrid Reinforced Epoxy Composites: Effect of Surface Modifications

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ABSTRACT: The present experimental work is aimed to study the effect of different loading rate on mechanical behaviour of jute/glass reinforced epoxy hybrid composites. Surface modification was done in order to get better interfacial bonding between jute and resin. Hybrid composite showed insensitive behavior at high loading rate. The loading rate behavior of the hybrid composite was compared on the basis of different surface treatments of jute fiber. UV-treated samples have shown better yield properties at higher loading rate. Untreated samples exhibited better ILSS values at higher loading rate. The findings are explained in terms of varying failure mechanisms at different loading rates.

KEY WORDS: composites, natural fiber, jute/glass fiber, hybrid composites, surface modifications, loading rate, shear strength.

INTRODUCTION

Fiber–reinforced polymer matrix composites are gaining potential application in structural and nonstructural areas due to having the interesting properties like high specific stiffness and strength, good fatigue performance and damage tolerance, corrosion resistance, low thermal expansion, non-magnetic properties, and low energy consumption during fabrication [1, 2, 3]. Different loading conditions are expected in many of the applications where fiber–reinforced polymer (FRP) composites find use as potential and promising materials. Composite materials are expected to be exposed to variations in loading rates when used in practical conditions. The effect of loading rate variations are investigated by many researchers and they have found many contradictory results, so the exhaustive research study is expected in this area to extend the areas of application of these materials and understanding their failure mechanisms under different loading conditions [4]. Mechanical properties of such composites change with the strain rate to which they are subjected to [5]. Various approaches have been made to improve the damage tolerance (low-velocity or low- energy impact) or penetration resistance (high- velocity or high energy impact) of composites materials. However, the most effective and applicable approaches are fiber hybridization, and use of high-strain fibers. The development of composites by incorporating more than one type of fiber reinforcement (hybrid composites) is motivated by the ability to an added degree of freedom to tailor the properties of composites for achieving a better balance of stiffness and strength, increased failure- strain, better damage tolerance, improved ability to absorb impact energy and possibly a significant reduction in cost by utilizing advantageous features of various fiber systems [6]. Natural fiber is gaining potential application as reinforcement because it is advantageous over others as these are easily available, biodegradable, low-cost materials with attractive properties like low abrasive nature which is beneficial in sense of processing techniques and recycling etc. Besides having these advantages there are also some bottlenecks like poor compatibility with the hydrophobic polymer matrix, the tendency to form aggregates during processing and the low resistance to moisture related to these fibers greatly reduce the potential of natural fibers to be used as reinforcement for polymer matrix composites[7]. The most important problem is the fiber-matrix adhesion because load is transferred to stiff fibers through shear stresses at the interface and it requires a good bond between the polymeric matrix and the fibers. Due to the presence of pendant hydroxyl and polar groups in various constituents of the natural fiber resulting in poor wettability and also moisture absorption of the fiber is too high, giving rise to poor interfacial bonding with the hydrophobic matrix polymers. Therefore surface modification is necessary to improve the fiber-matrix adhesion to obtain better performance composites. The surface properties of the natural fiber may be improved by physical treatments (cold plasma treatment, corona treatment) and chemical treatment (maleic anhydride, organosilanes, isocyanates, sodium hydroxide, permanganate and peroxide) [8, 9]. Surface modifications not only reduce the moisture absorption but also improve wettability of the fibers by the matrix polymer and the interfacial bond strength, both are essential to impart better mechanical properties to the composites [10]. An alkali treatment result in dissolution of non-cellulosic component hemicellulose and lignin, destruction of mesh structure and splitting the fibers into finer filaments termed as fibrillation, thereby increasing the effective surface area wetting by the resin and thus improves the interfacial bonding between fiber and the matrix by giving rise to additional sites of mechanical interlocking. And alkali treatment also increases crystallinity and fiber elongation characteristics which improves the fiber strength properties. Dissolution of hemicellulose results less dense and less rigid interfibrillar region. Which makes the fibrils more capable to rearrange themselves along the direction of deformation, leading to better load sharing and hence results in higher stress development in the fiber, giving rise to better mechanical properties, and lignin removal imparts plasticity to the cell structure resulting in better properties to the fiber [11, 12, 13, 14, 15, 16]. UV- treatment increases the polarity on the fiber surface by increasing the concentration of carboxyl-groups on the fiber surface, consequently improves the wettability of the fiber and the composite flexural strength. Elevated temperatures (during long time exposure with high energy of UV radiation) result in rapid increase of the surface density of these polar groups. Excessive treatment leads to degradation of fiber tenacity [17].

From literature, it seems, there are very few paper which deals with the loading rate sensitivity of hybrid fibers-reinforced polymer (FRP) composites and which is of high importance as FRP composites are widening its areas of application where loading rate insensitivity of the material is highly desirable. This present experimental paper is an attempt to study the effect of loading rate variation on differently treated jute / glass fiber hybrid polymer matrix composite and also to make a comparison of the effect of surface treatment of jute-fiber on the loading rate behavior of the hybrid composite. And further the fracture surfaces of the composites were examined to investigate the nature of failure under different loading conditions.

EXPERIMENTAL

1. SURFACE TREATMENT:

(a) ALKALI TREATMENT

First the jute fiber was treated in a solution of 5% NaOH where the total volume of solution was 15 times the weight of jute fibers. The fabric was kept in this alkaline solution for 45 minutes at a temperature of 50˚ C inside an oven; it was then thoroughly washed in running water then neutralized with a 2% acetic acid solution. Lastly it was again washed in running water to remove the last traces of acid sticking to it, so that the $_{p}H$ of the fibers is approximately 7 (neutral). Then they were dried in open for 24 hrs, and then oven dried at 110˚ C for 3 hrs.

(b) UV-TREATMENT

The jute fiber fabric cut into proper sizes were put inside the UV chamber, the substrate was put at a constant distance from filament and then subjected to a shorter wavelength of UV radiation (254nm), for 10 minutes.

2. FABRICATION:

HANDLAY-UP TECHNIQUE

The jute fiber and the glass fiber were cut to standard size square sheets.The jute fabric was then Alkali treated, or UV treated. Araldite

LY-556, an unmodified epoxy resin based on Bisphenol-A and the hardener (Ciba-Geig, India) HY 951 (10% of total Epoxy taken) an aliphatic primary amine, were mixed properly. The milder sheet was then laid on a flat surface, on to which mold release spray was sprayed, then a layer of epoxy was coated on the sheet, now alternately, layers of jute fiber fabric and glass fiber fabric were laid one upon other, with a layer of resin in between two such fabric. At the last again a milder sheet was taken and mold release sprayed on to it, and then a layer resin mix was applied to it. And this was put on to the last layer of the composite. A flat board was then put on this sheet and dead loads were applied on to this prepared composites above this board, and this was then allowed to cure for around 24 hours, after which the prepared sample was ripped off the mold.

3. PREPARATION OF SPECIMEN AND TESTING:

The laminates were cut into short beam shear test specimens of width 6mm and length 45mm by diamond cutter. Then the SBS 3-point bend tests were conducted to determine the interlaminar shear strength and flexural strengths of these specimens. The 3-point bend tests were carried out at different cross head speeds of 2, 50,100, 200, 500 mm/min with an Instron - 1195 tensile testing machine in accordance with the ASTM D 2344-84 standard. Minimum five samples were tested at different crosshead speed and the average value was reported. The interlaminar shear strength was measured as follows:

$$S_H = \frac{o.75P_b}{bd}$$

Where S_H is the ILSS, P_b the breaking load, b the width of specimen, d is the thickness of the specimen.

RESULTS AND DISCUSSIONS

Figure: 1 shows the variations of stress at yield with increase of crosshead velocity. It is obvious from the initial stage of graph (2-50mm/min) that stress at yield increases with increase of cross-head velocity due to increase in stiffness of the composite with increasing loading rate. In the middle range of loading rate (50-100mm/min), the stress at yield decreases with increase in loading rate due to brittle behaviour of matrix in that range and/or less time available for crack blunting. In later stage stress at yield increases and at higher loading rate it becomes constant which shows the insensitivity of composite with loading rate in terms of stress at yield with increase of crosshead velocity, the cause may be attributed to energy absorbing behaviour of jute-fibre which might be more predominant at higher loading rates. The figure also shows the better performance of ultra-violet treated sample than the untreated and alkali treated samples at higher loading rates. The untreated sample show better response at high loading rate than alkali treated sample. The reason may be attributed to predominant fiber pull-out failure mechanism in untreated sample, unlike alkali treated sample where fracture of resin and matrix both occur simultaneously resulting in load-drop [18].

Figure: 2 shows the variations of displacement at yield with increase of crosshead velocity. In first stage of graph, displacement at yield increases with increase of crosshead velocity (2-50mm/min). Further (50-100mm/min), it decreases as less time available for blunting the crack tip leading to brittle failure, as here matrix cracking is the primary failure mechanism and it propagates via interfacial debonding. And as crosshead velocity increases further the displacement at yield increases and becomes constant at higher loading rate. Final stage of graph shows the insensitivity of composite in terms of displacement at yield with increase of crosshead velocity. And here also UV-treated sample shows the better performance, giving higher displacement at yield at higher loading rates. The reason may be the improvement in fiber elongation properties due to UV-treatment, but it is still to be verified by further research.

Figure: 3 shows the variation of inter-laminar shear strength with increase of crosshead velocity. Behavior is almost same in first two stages as first increase with increase of crosshead velocity and then decrease with the increase of crosshead velocity. The decrease of ILSS value may be attributed to less time available for crack-blunting in this range of crosshead velocity (19). But the very surprising change in behavior at higher crosshead velocity which shows insensitivity with increase of crosshead velocity with maximum ILSS value for untreated sample. It may be attributed to change in failure mechanism with increase of crosshead velocity. Fiber-matrix adhesion leads to brittle failure. Fiber bunch pull-out may be the predominant mode of failure in untreated sample which is more energy absorbing than fiber fracture which is predominant mode of failure in case of weak interfacial- bonding at higher loading rate (8). The strong fiber-matrix adhesion results in brittle failure in the fibers since the interfacial bonding influences the intralamina strength, the interlaminar shear strength and the interlaminar tensile strength. The observed pull-out of fibers is dependent on the bond strength and the load transfer mechanism from matrix to fiber (20). The same findings were also reported by S. Mohanty et al. (21), that poor interfacial bonding between fiber and matrix leads to higher energy dissipation.

From the SEM micrographs 4(a), 4(b), 4(c), and 4(d) it is obvious that at low crosshead velocity the occurrence of cohesive failure of matrix with cracking along with intact fibers may be the predominant failure mechanism. At an intermediate loading rate composite showed the debonding and resin fracture followed by the fiber breakage and pull-out 4(e), 4(f). At higher loading rate, the SEM micrograph 4(g), 4(h), 4(i), 4(j) illustrate the extensive fiber fracture and pull-out with localized matrix damage followed by extensive delamination.

The observations from the SEM micrographs may be attributed to varying failure mechanisms with varying loading rate, fiber kinking coupled with the micro-buckling and fiber fracture at low strain rates and combination of global delamination, interfacial separation and spalling at higher strain rates (22).

CONCLUSION

In this present experimental study, the loading rate behavior of jute/glass fibers hybrid epoxy composite were examined and reported. some very interesting and useful results viz. the loading rate insensitivity of hybrid composites in sense of stress at yield, displacement at yield and ILSS values at higher loading rate were obtained which is explained on the basis of changing failure modes as the crosshead velocity changes. UV-treated samples have got better properties in sense of stress at yield and displacement at yield at higher loading rate with increase of crosshead velocity. ILSS values were reported higher in case of untreated samples as fiber pull-out is predominant failure mechanism which is more energy absorbing mechanism than fiber fracture which is prevalent in case of surface treated samples. Here mechanical properties were shown loading rate insensitive at higher loading rate which is of much concern nowadays as the application areas of polymer based composites are getting widen. But further more research is expected to establish the findings in a more concrete way with the change in parameters related to experiment and surface treatment of jute fiber to accomplish better property hybrid composites.

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FIGURE CAPTIONS

Figure 1 Variation in stress at yield with the change in crosshead velocity in jute fiber-glass fiber/hybrid epoxy composite having jute fiber untreated (♦), alkali treated (▲), and UV treated (■).

Figure 2 Variation in displacement at yield with the change in crosshead velocity in jute fiber- glass fiber/hybrid epoxy composite having jute fiber untreated (♦), alkali treated (▲), and UV treated (■).

Figure 3 Variation in interlaminar shear strength (ILSS) with the change in crosshead velocity in jute fiber- glass fiber/hybrid epoxy composite having jute fiber untreated (♦), alkali treated (▲), and UV treated (■).

Figure 4 (a) Matrix failure with intact fiber (at 2mm/min crosshead speed)

Figure 4 (b) Matrix cracking

Figure 4 (c) Cohesive Matrix Damage with intact fiber

Figure 4 (d) Cohesive Matrix Damage

Figure 4 (e) Debonding

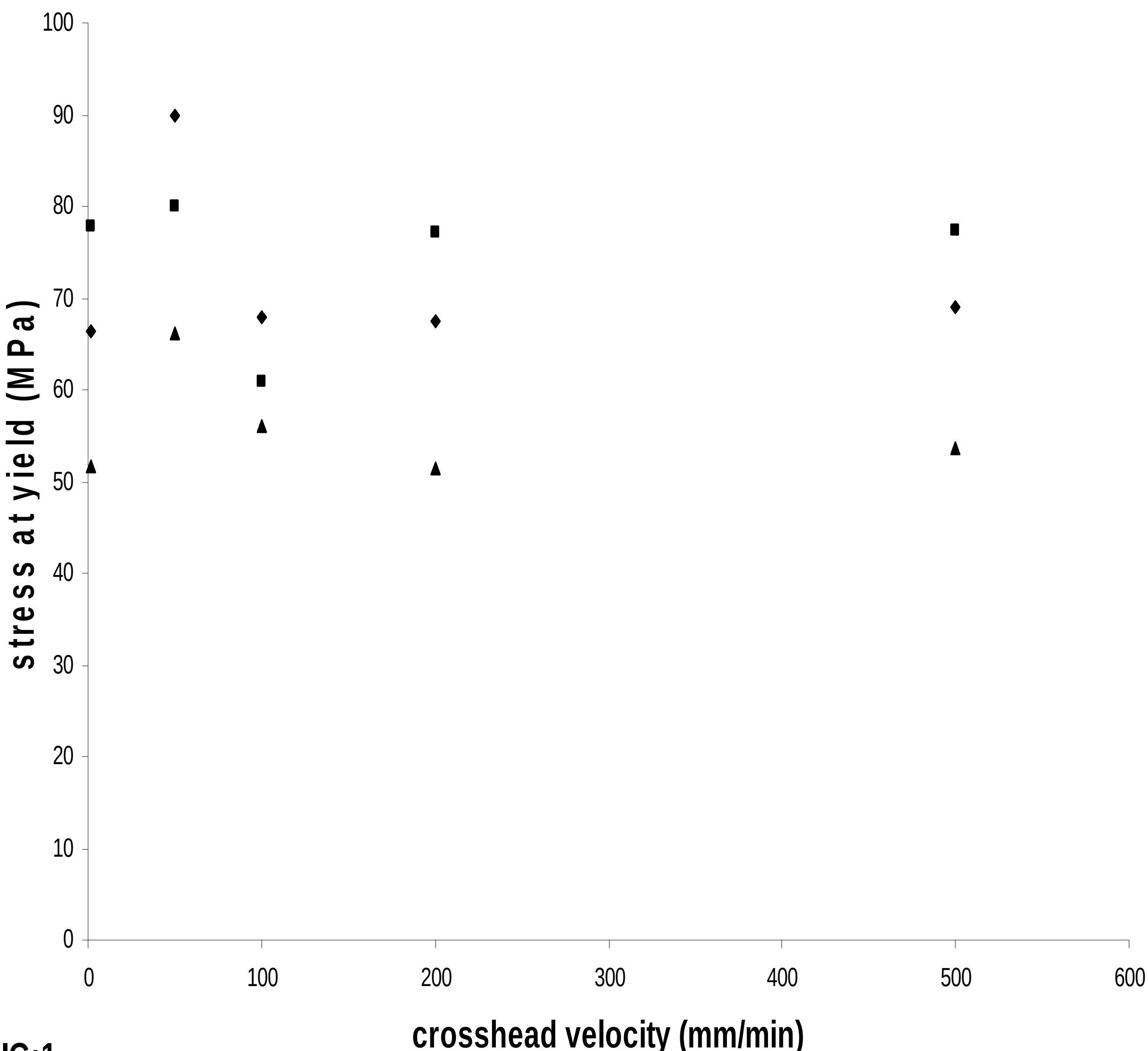
Figure 4 (f) Fiber Pull-out

Figure 4 (g) Extensive fiber pull-out and fiber fracture (at 500 mm/min)

Figure 4 (h) Extensive fiber pull-out and fiber fracture

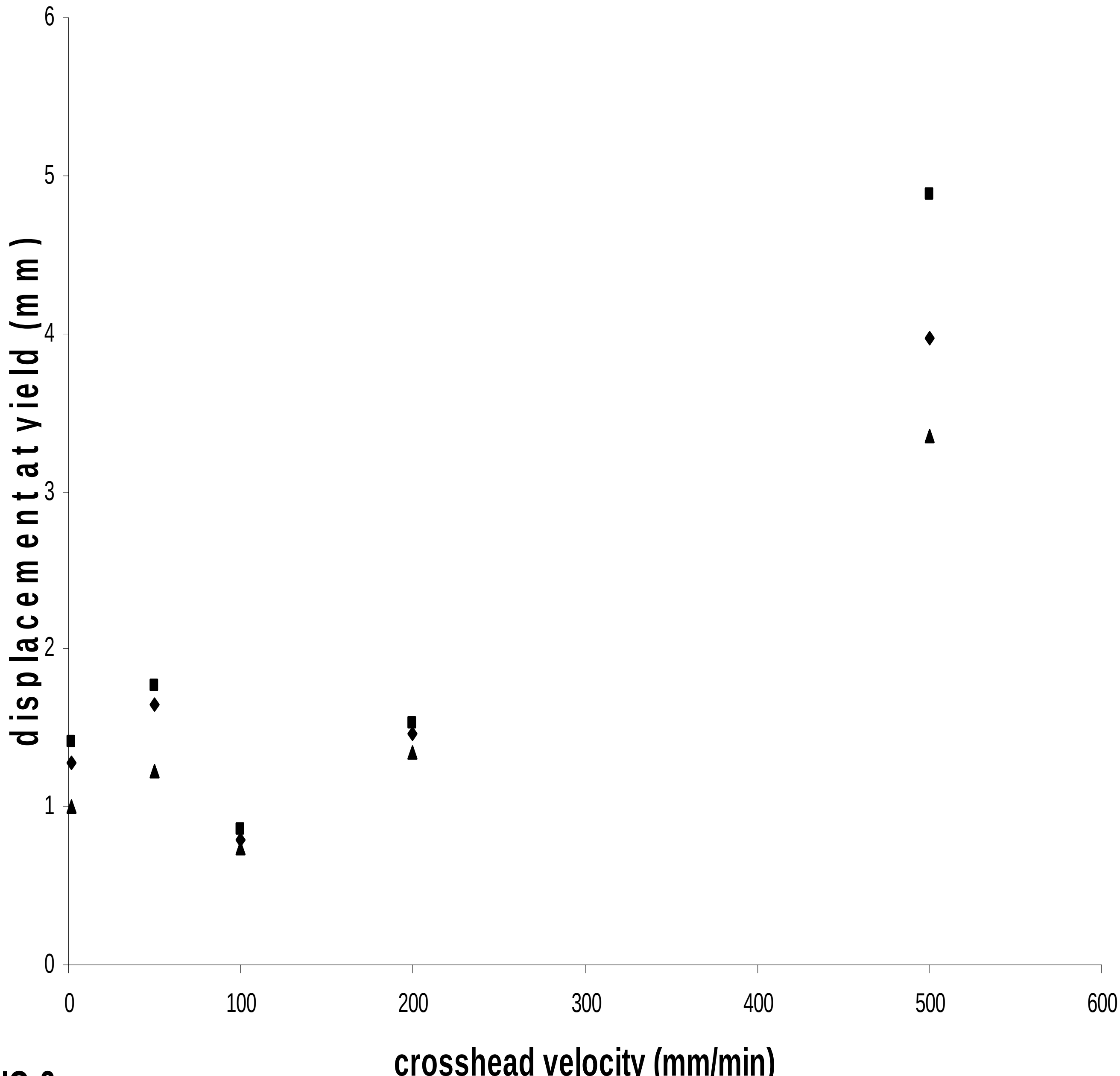
Figure 4 (i) Extensive fiber pull-out and fiber fracture

Figure 4 (j) Extensive Delamination



stress at yield (MPa)
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
crosshead velocity (mm/min)

FIG:1



6
5
4
3
2
1
0
0
100
200
300
400
500
600
displacement at yield (mm)
crosshead velocity (mm/min)

FIG:2

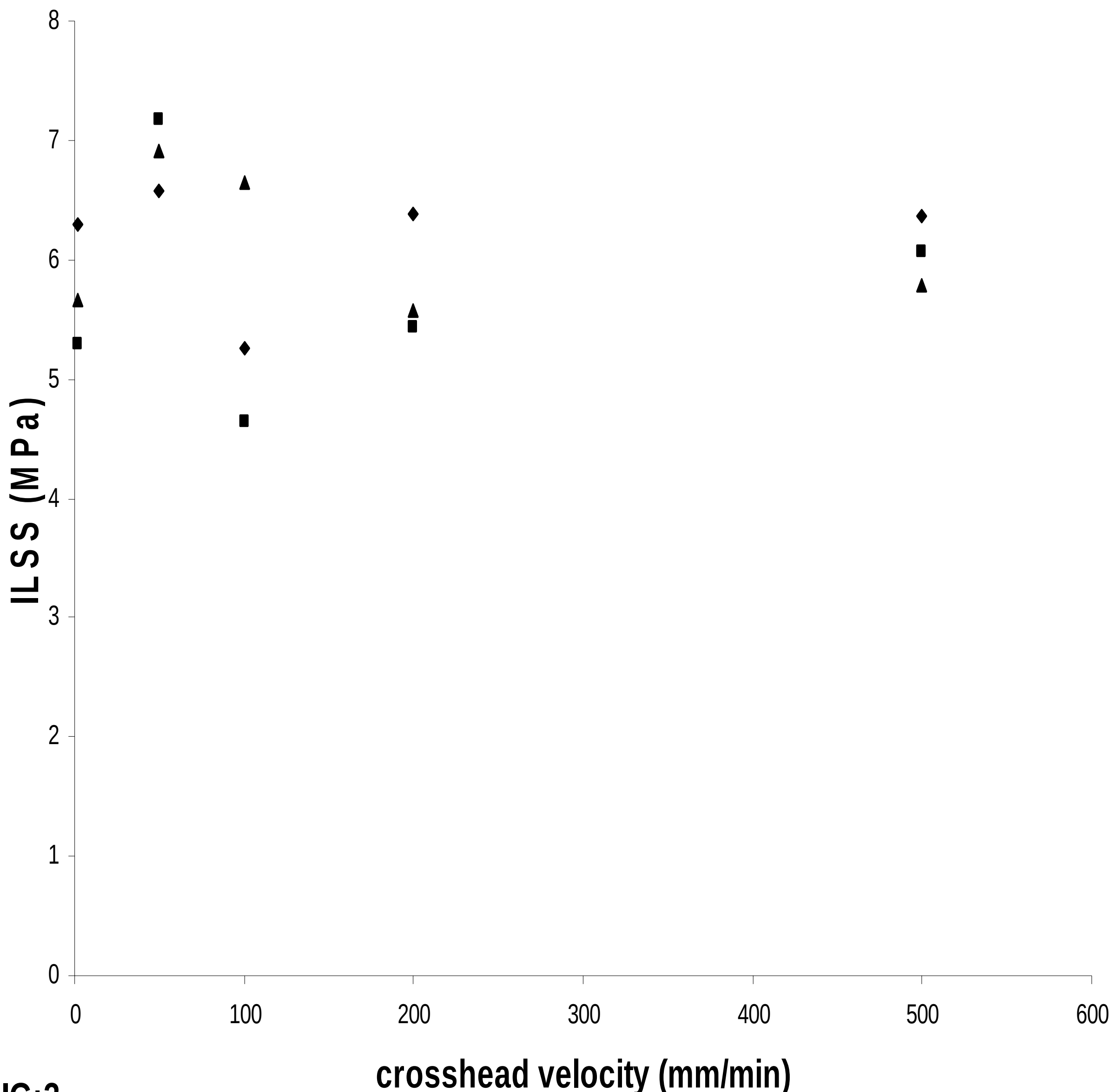

ILSS (MPa)
0
1
2
3
4
5
6
7
8
0
100
200
300
400
500
600
crosshead velocity (mm/min)

FIG:3

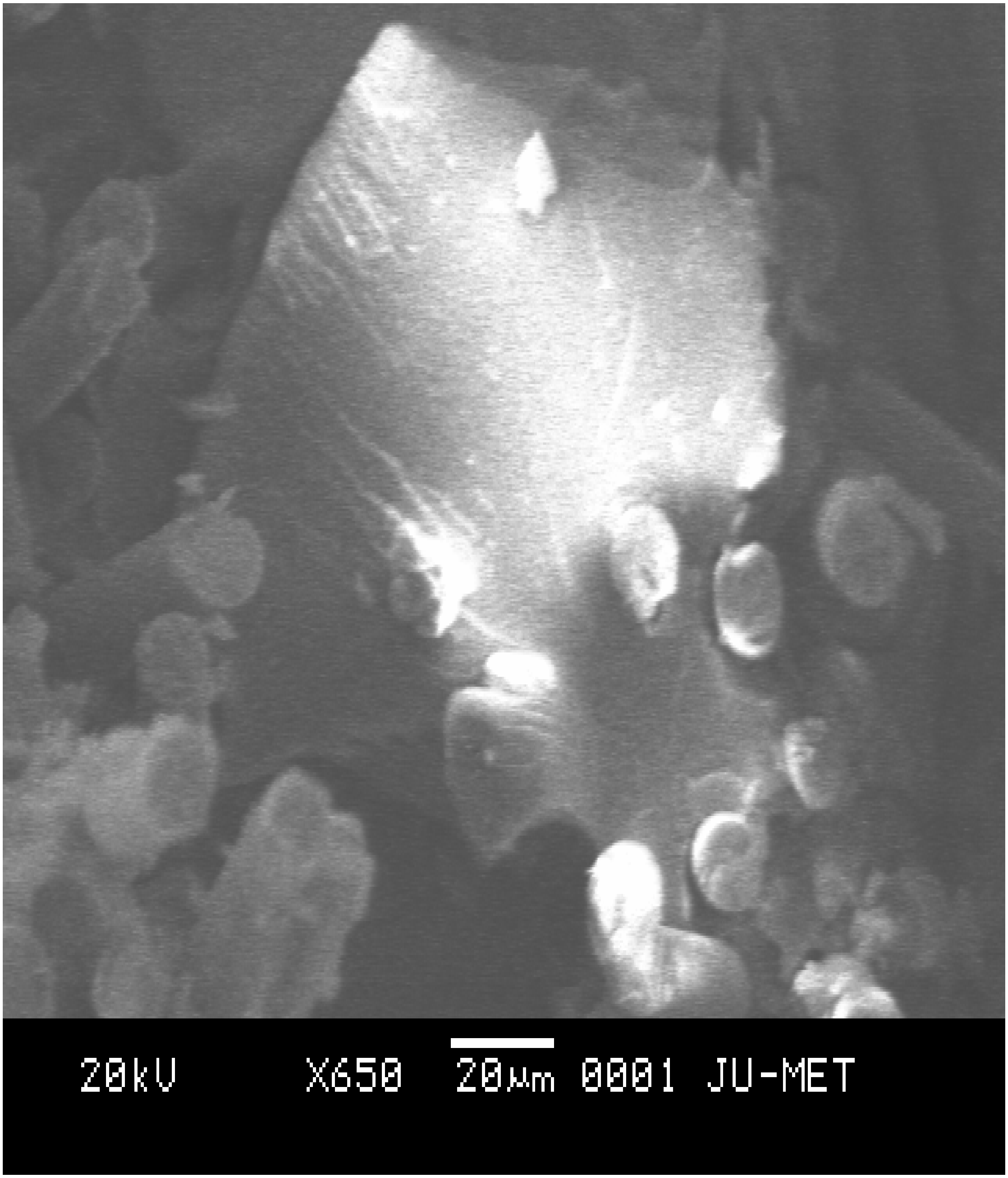


FIG: 4(a)

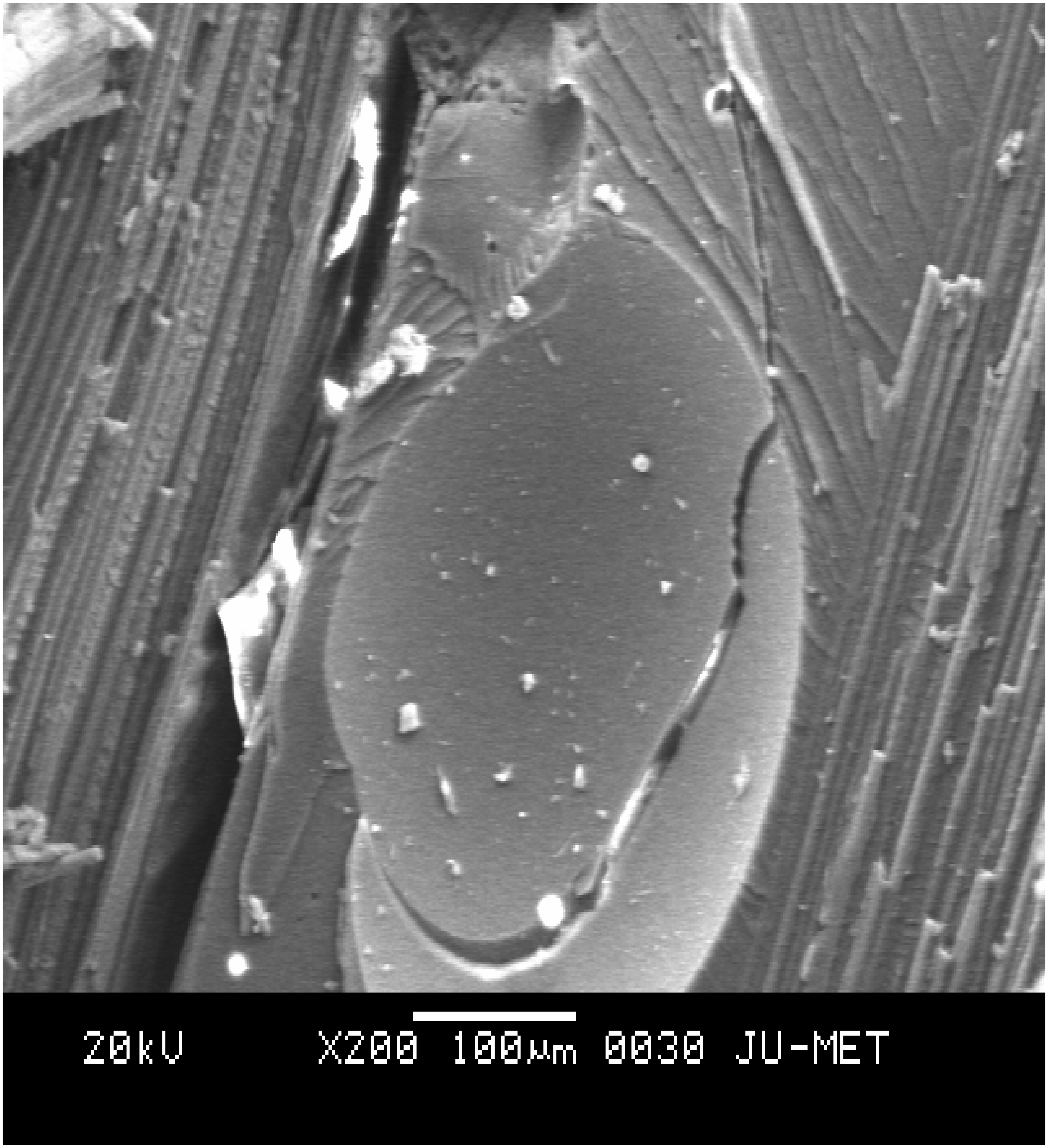


FIG: 4(b)

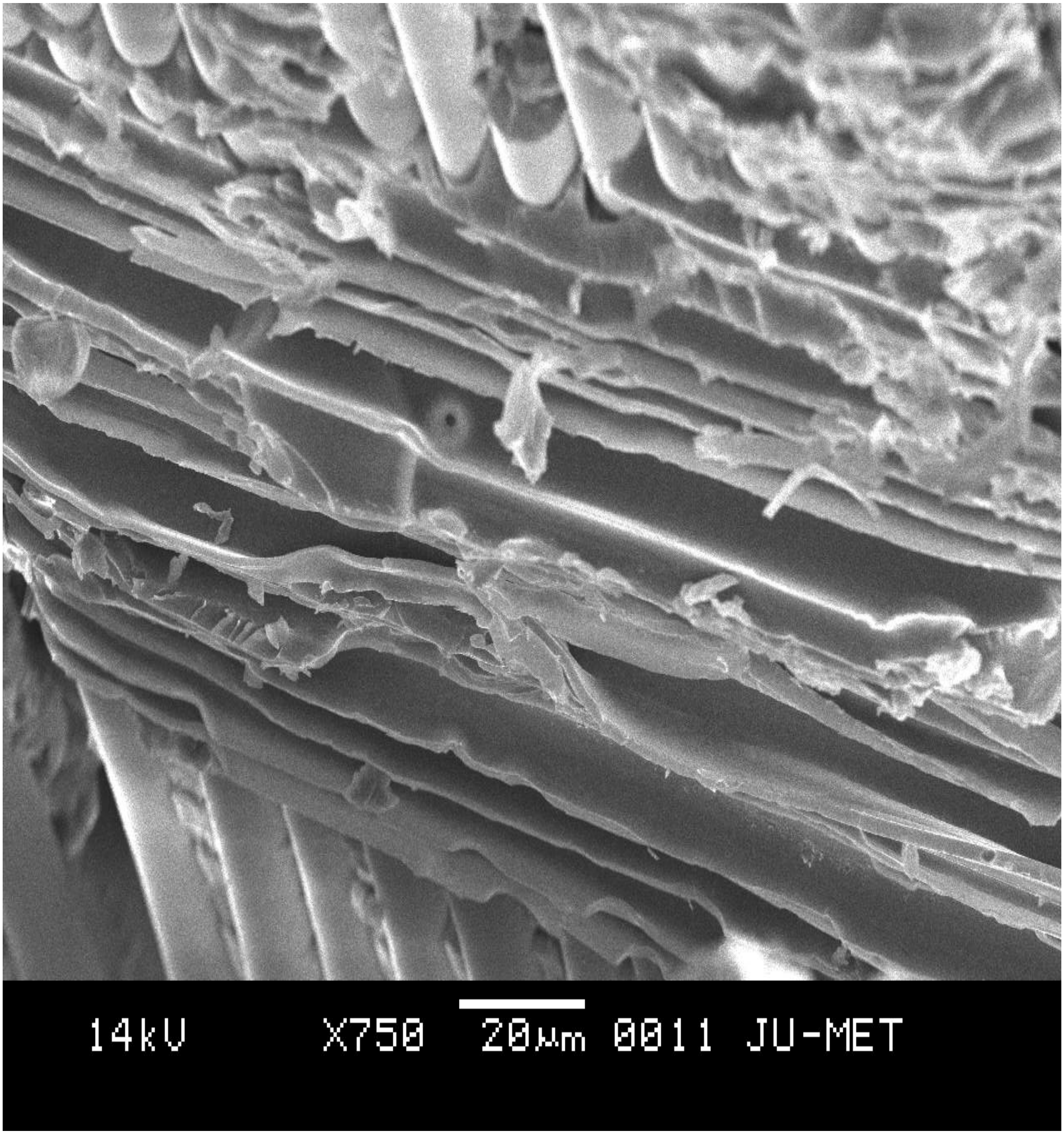


FIG: 4(c)

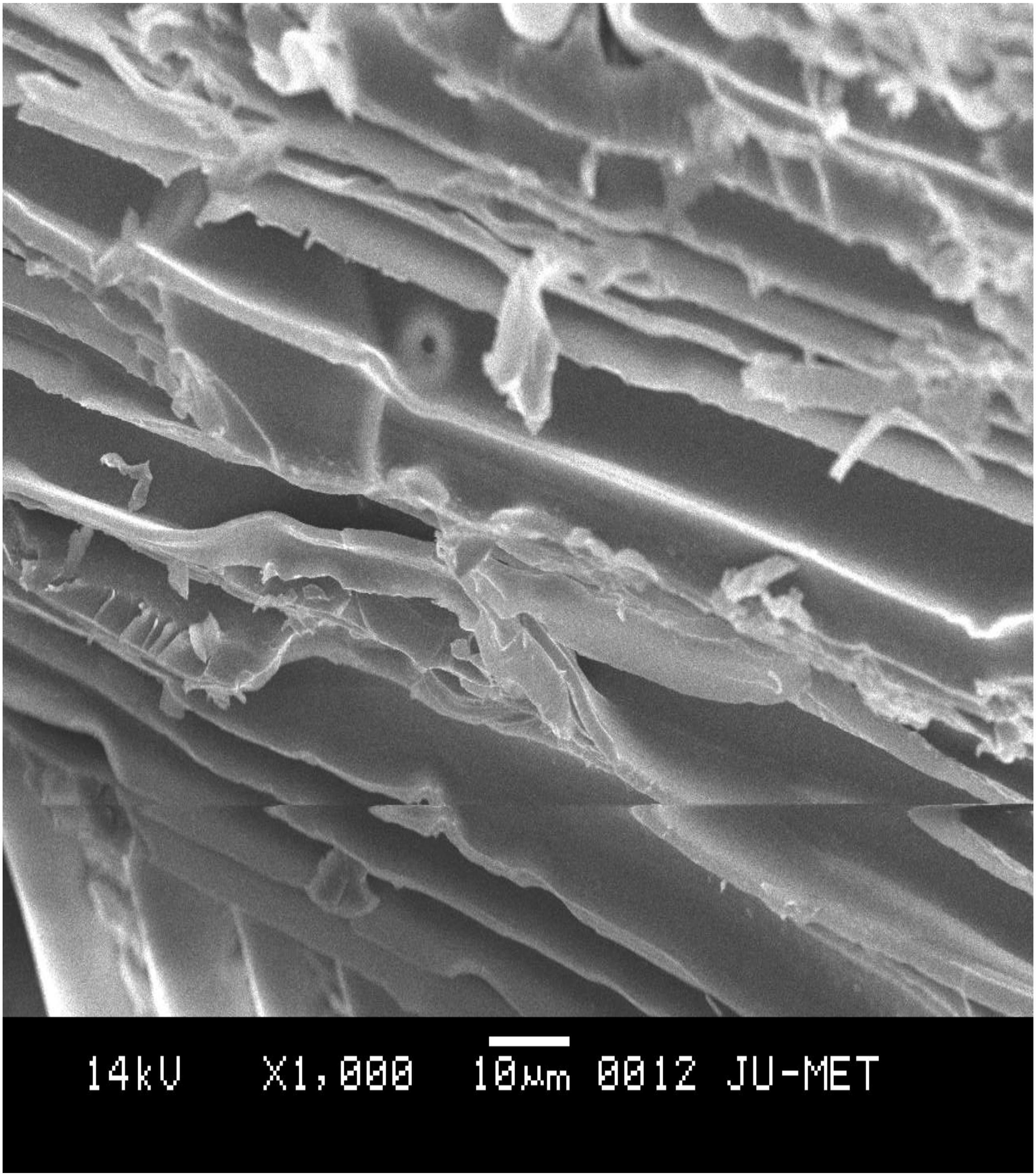


FIG: 4(d)

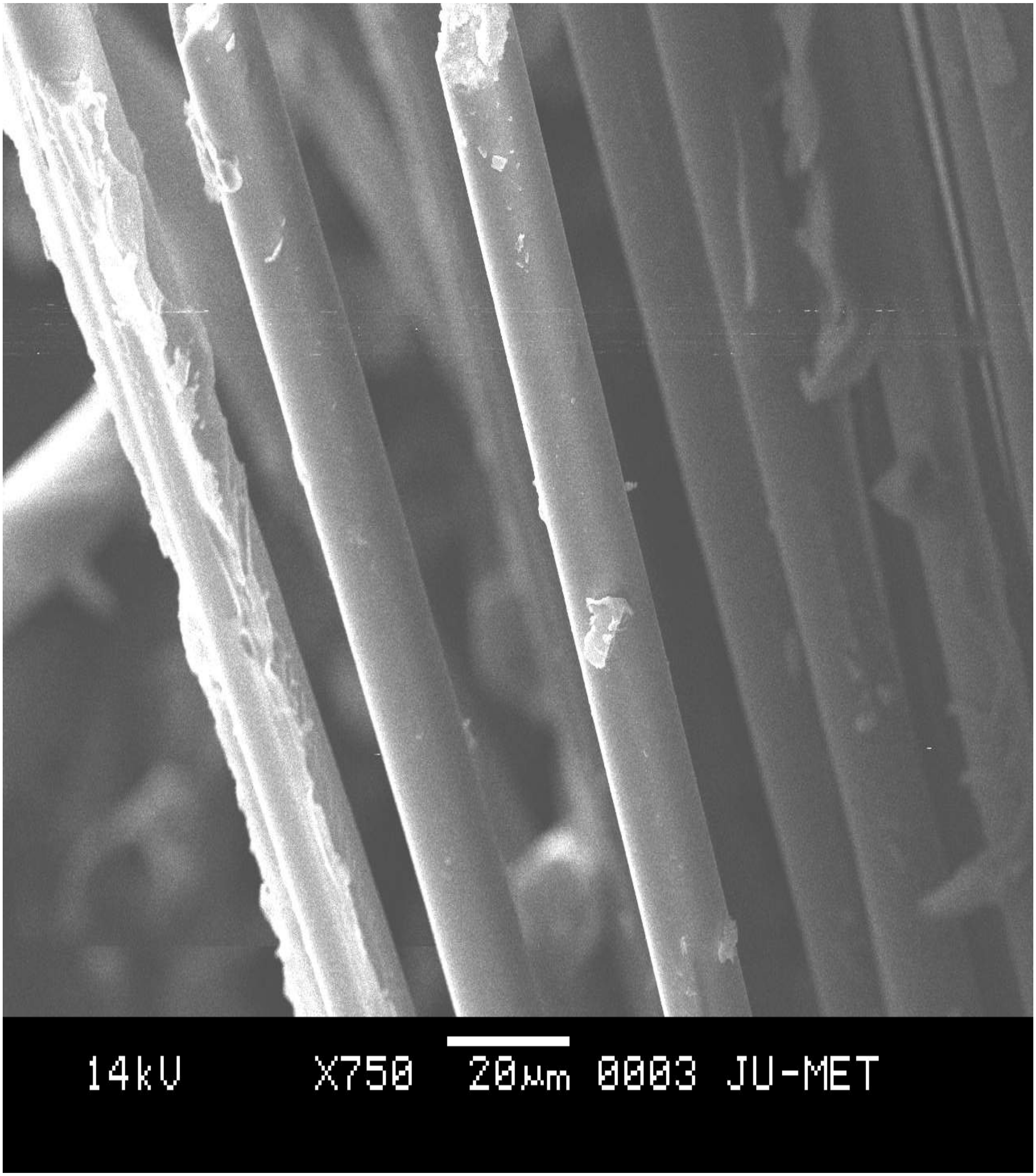


FIG: 4(e)

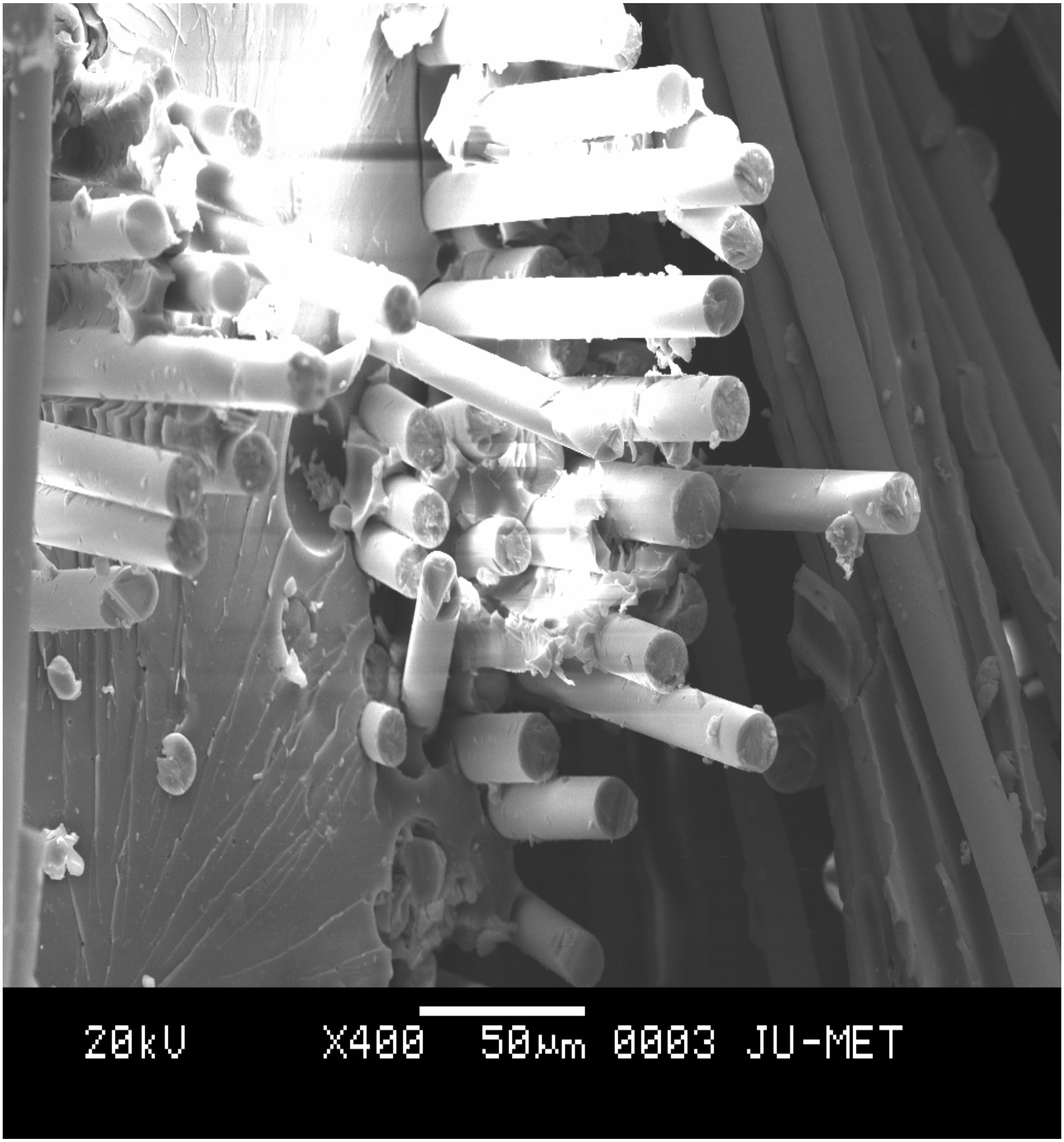


FIG: 4(f)

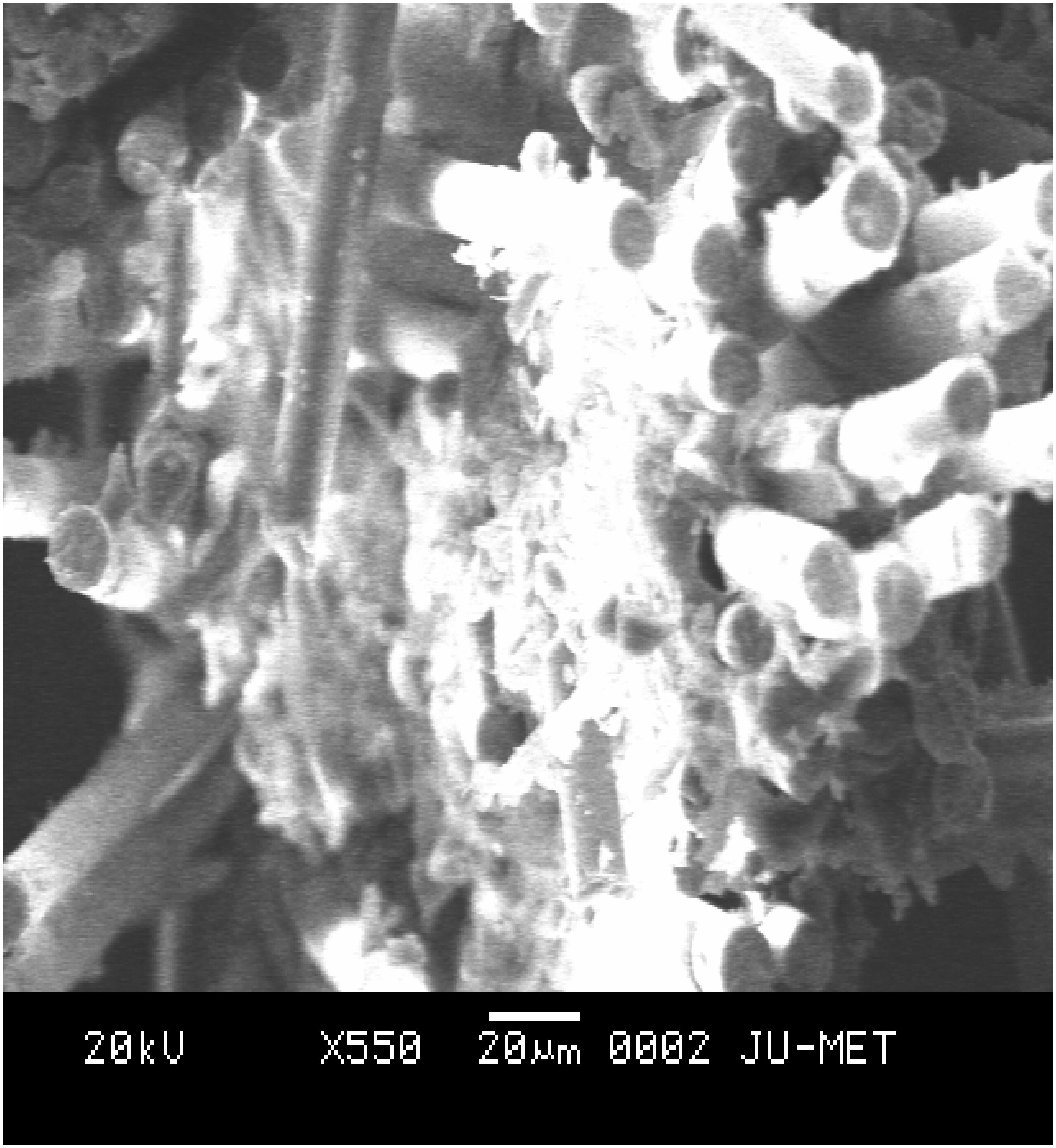


FIG: 4(g)

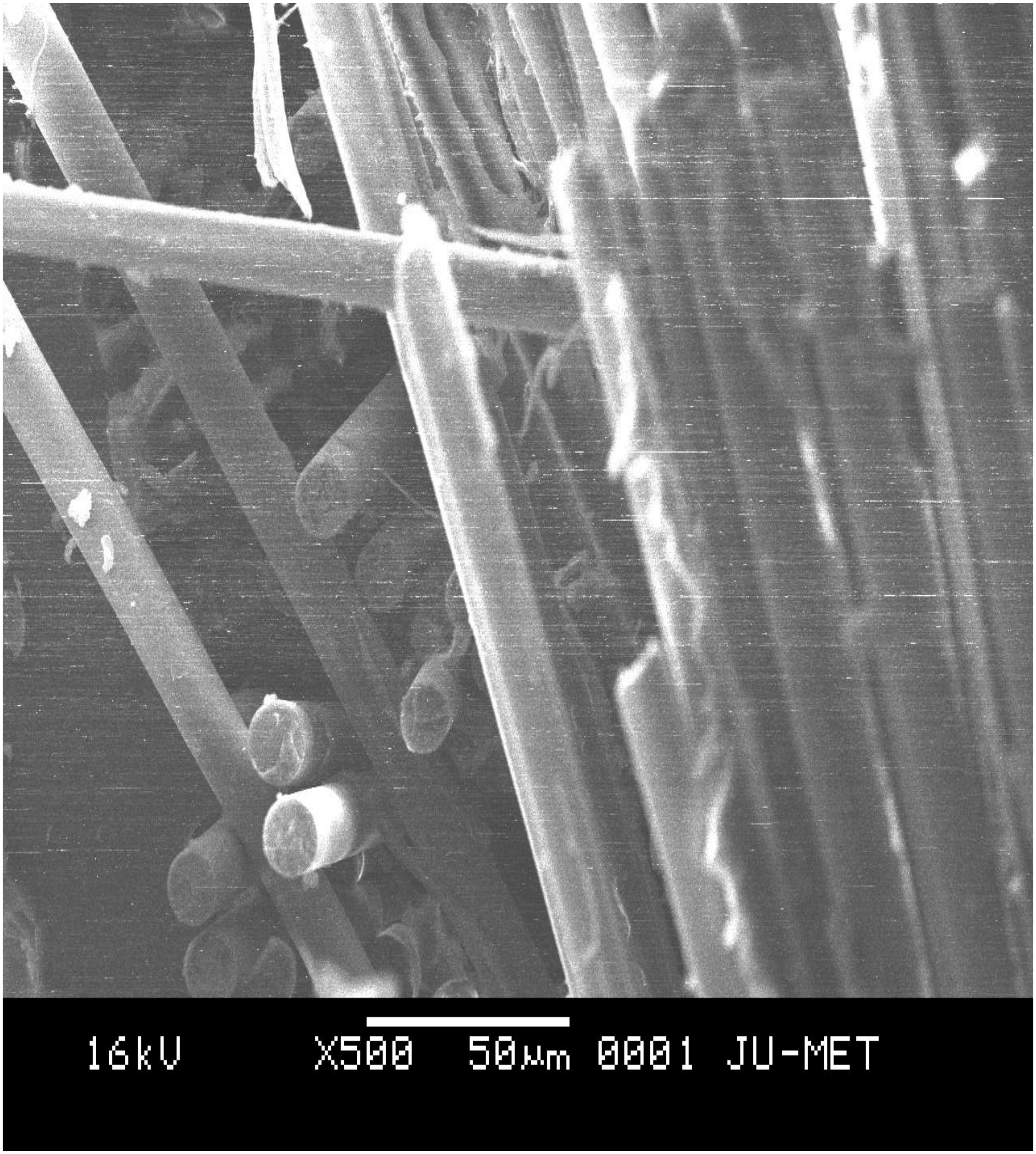


FIG: 4(h)

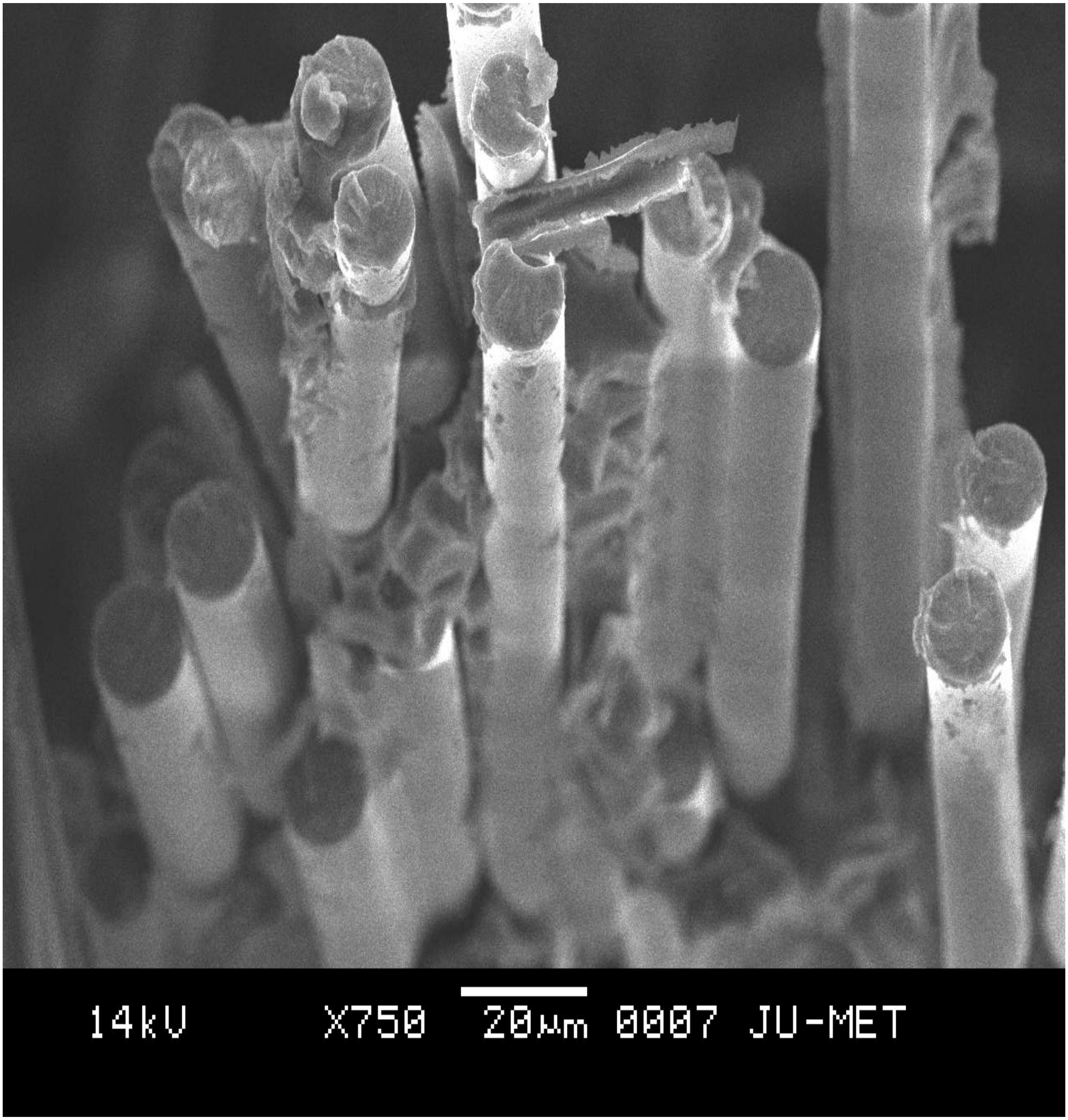


FIG: 4(i)

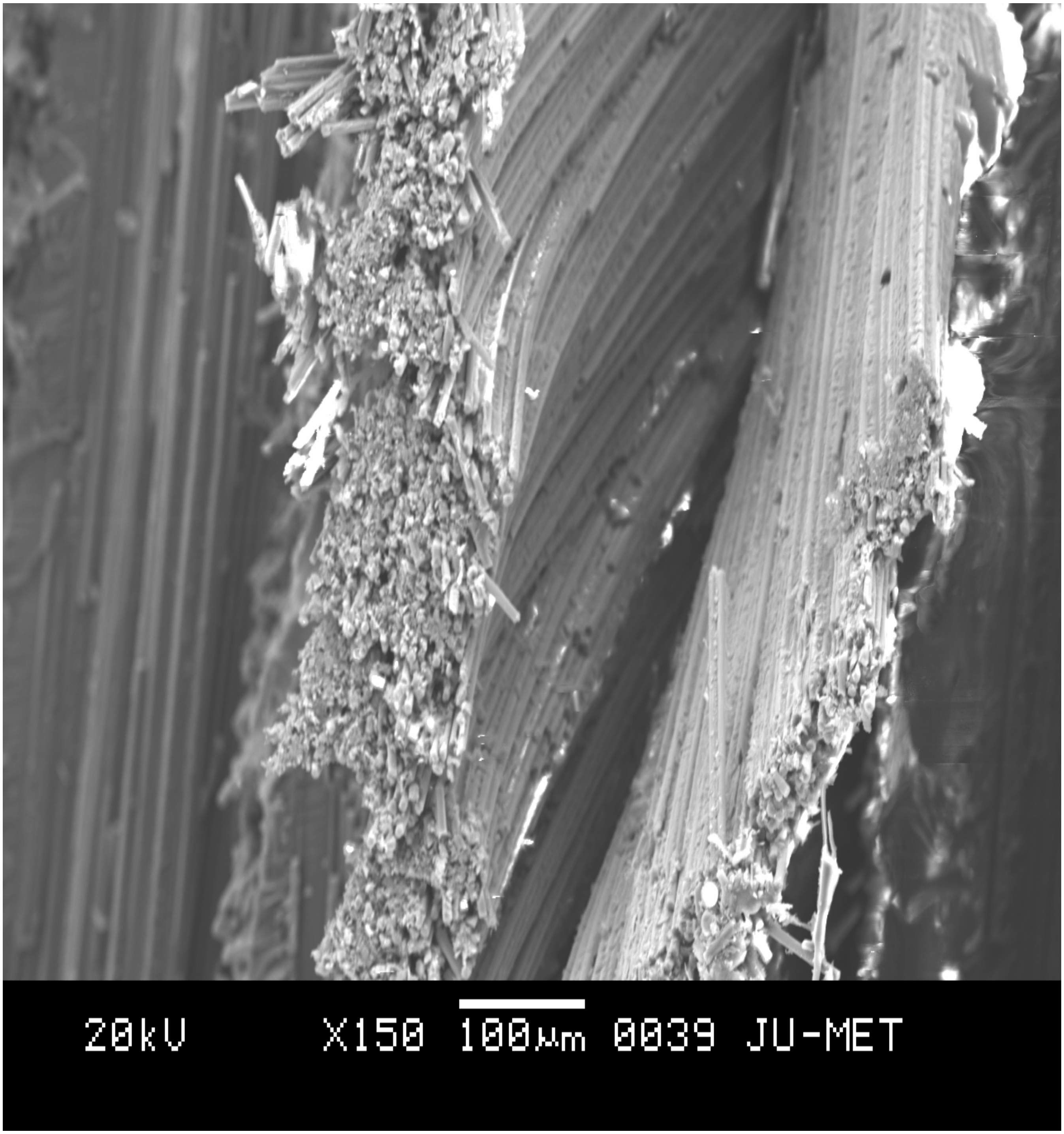


FIG: 4(j)