The Effect Of Potassium Permanganate On *Betung* Bamboo (Dendrocalamus Asper) Epoxy Fiber Compositesusing Hand Lay Up Method

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ABSTRACT

The application of natural fiber composites in the modern world is often overlooked due to the rise of new synthetic fibers. The *Betung*Bamboo is one type of natural fiber that has been used for many generations in the Indonesian archipelago. The fiber can be used to produce composites, however the choice of matrix and fiber treatment has an effect on determining the strength properties of the composite. In this study using epoxy resin as a matrix and *Betung* Bamboo fiber as a filler. Permanganate treatment of *Betung* bamboo fiber was conducted using $KMnO_4$ solution. With variations in KMnO4 concentrations of 3%, 5%, and 7% for 15 minutes of immersion. The fabrication was carried out by hand lay-up method with silicone rubber molds. Tensile tests are then carried out to determine the tensile strength of the composite. Digital microscopy was observed to see the fracture pattern of the composite. The initial hypothesis of this study was the treatment of $KMnO_4$ solution which aims to improve the interfacial properties of strength and resistance of *Betung* bamboo fiber and matrix, so that the mechanical properties of the composite are stronger. The highest tensile strength was at 5% $KMnO_4$ content of 33.55 MPa and the lowest was at the specimen without $KMnO_4$ content of 28.06 MPa. The highest strain was on specimens without $KMnO_4$ content with 2.645% and the lowest on 7% $KMnO_4$ content with 1.513%. The highest elastic modulus value was at 7% $KMnO_4$ content of 20.84 MPa and the lowest was for specimens without $KMnO_4$ content of 10.6 MPa. In the tensile test specimen without $KMnO_4$ content, there are pullout fracture patterns, and in the tensile test specimen with 5% $KMnO_4$ content there are indications of overload fracture pattern.

KEYWORDS
Composite
Betung Bamboo
$KMnO_4$
Epoxy Resin
Tensile Properties

1. Introduction

In the manufacture of vehicles, especially in private vehicles such as cars, car body frames more often use metal materials, such as steel and aluminum.[1], [2]. Steel material, even though it has good material strength, often has a heavy weight [3]. The weight of this vehicle will directly affect several aspects of the vehicle such as speed and energy consumption in the vehicle [4]. For vehicles that want to focus on energy saving (e.g.energy efficient cars), this aspect is important for consideration. For this reason, other materials such as composites which have a lighter weight than metal materials can be a good alternative to use[5].

Composites for car frames that are often used are composites with carbon fiber [6], [7]. However, making a car body with carbon fiber requires a relatively expensive price. Natural fiber can be a substitute for carbon fiber at a cheaper price and is more environmentally friendly [8]. One example that is light and relatively strong is *Betung*bamboo fiber which has the potential to replace glass fiber and is environmentally friendly[9].

International Journal of Engineering and Applied Technology (IJEAT)
Vol. 5., No. 2, November 2022, pp. 36-44

Natural fibers generally produce strength that is not equivalent to carbon fiber[10]. This is because the main drawback of the material is that it is not compatible with thermoplastics due to its hydrophilic character[11]. This results in poor interface interaction between the fiber and the matrix. So natural fibers must be modified so that they are not too hydrophilic[12], [13].

Some efforts can be done to overcome this such as special potassium permanganate chemical treatment to improve the interfacial properties of the material strength. Imoisiliet. al. have conducted research using $KMnO_4$ on horn banana natural fiber, with the highest tensile test results of 46 MPa with 0.05% $KMnO_4$ content, compared to no tensile strength treatment of 23 MPa[14]. Mohammed et. al. has also conducted research related to the effect of potassium permanganate on palm sugar fiber[15]. This study showed that treatment with 0.125% potassium permanganate resulted in stronger tensile strength than alkalization treatment with 6% sodium hydroxide. The highest tensile strength is 9 MPa, whereas with sodium hydroxide alkalization treatment it is less than 6 MPa[16].

There are many methods used to ($KMnO_4$) make composites but Hand Lay Up is a method often chosen to manufacture and research the properties of composites. The Hand Lay Up process is simple, gives good composite quality and has good consistency. This method is compatible with Permanganate treatment and can be then used to understand the effect of $KMnO_4$ levels on the tensile strength of the epoxy fiber composites. The potassium permanganate treatment process on *Betung* bamboo is to improve the interfacial properties of the material strength. Treatment with a small amount of potassium permanganate was proven to be able to increase tensile strength compared to no treatment and sodium hydroxide treatment [17].

Composite is defined as a material consisting of two or more components that have different properties or structures which are physically mixed together to form a mechanical bond to produce a new material that has superior properties than the forming material[18]. Bamboo is one of the natural fibers which are abundant in Indonesia, one of the types of bamboo that exists is *Betung* bamboo (Dendrocalamus asper). *Betung* bamboo has quite good characteristics, besides its relatively cheap price, this bamboo is also environmentally friendly to be applied in composite materials. Other properties also show that the strength of this bamboo is quite high and its bending and impact strength is also high to be applied in vehicle interiors.

Epoxy resin is a type of thermoset resin or plastic that cannot change due to heat (cannot be recycled), thermoset plastic can withstand high temperatures so that after it hardens it cannot be reshaped or recycled but this type of resin has advantages in terms of strength high and relatively small shrinkage after curing[19]. Including this and the previous mentioned materials and methods, this study is conducted to understand the effect of permanganate treatment concentration on Epoxy *Betung*bamboo composites.

2. Method

2.1. Materials and Tools

The materials used in this study are epoxy resin (Bisphenol A-Epichlorohydryn) as a matrix, Hardener (Clycloaliphatic Amine) as a resin hardener, *Betung* bamboo (Dendrocalamus asper) which is 2 years old as a fiber or filler in the manufacture of composites. NaOH solution was used to remove lignin, hemicellulose, and other extractive substances from the fiber. $KMnO_4$ solution is used for permanganate treatment of the fiber to strengthen the interfacial properties of the matrix and fiber strength in the composite. Silicon Rubber RTV-48 is used to make composite molding, and Catalyst RTV – SB is used for silicon hardener rubber.

The tools used in this study are vacuum pumps and resin traps to remove bubbles in the resin after being mixed with the hardener, roller machines for smoothing during the fiber manufacturing process, and molds for the process of making composite samples with the hand lay up method. Testing equipment used are Universal Testing Machine (UTM) which is used to determine the tensile properties of a composite is housed in the Polymer Laboratory BRIN (Badan Riset dan Inovasi Nasional) Puspitek Serpong.

2.2. Fiber Manufacturing Process and $KMnO_4$ Treatment

In the process of making this fiber using *Betung* bamboo (Dendrocalamus asper), *Betung* bamboo is made into sheets with a length of 20 cm with a diameter of approximately 1 mm per sheet, then the amboo fiber is soaked using 20% NaOH solution for 2 hours, with the aim is to dissolve elements such as lignin, hemicellulose, and other extractive substances. After that, cleaning of the fiber is done using a 2% HCL solution, which aims to remove the NaOH solution content. Resulting bamboo fiber is then rolled using a roller machine which aims to increase smoothness. This process is repeated many times until the fiber becomes finer. After the fibers have been made, they are put into the KMnO4 solution treatment process to improve the strength and resistance properties of the material interface between matrix and fiber. The variations in $KMnO_4$ levels in this study were 3%, 5%, and 7% with 15-minute soaking time and then dried in 24 hours.

2.3. Sample Making Process

In the process of making samples there are several properties that can be derived namely, V_{Komp} = 7,52725 cm^3, and dry *Betung* Bamboo Fiber density of ρs = 0,78 g/cm^3, Fiber Volume Fraction V_s = 5%. The manufacturing process uses the Hand Lay Up method with mold material from Silicon Rubber RTV-48 and Catalyst RTV – SB as the hardener. In the mold manufacturing process, it uses a 10:1 ratio with the mold size according to the tensile test sample. The stages of the manufacturing process are first the mold cleaned and then put on glass so that the composite does not stick to the mold when it is opened. A layer of fiber is placed on the mold as much as 5%, prepare enough epoxy resin and hardener then mix it evenly with a ratio of 2:1. After mixing, put it in the resin trap for vacuuming aims to remove bubbles in the resin, this process is carried out for 2 times 10 minutes with a pause of 5 minutes with a vacuum pressure of 2. Then pour the resin into the mold evenly, wait until it dries which takes approximately 1 day. Remove the composite sample from the mold then do the finishing for the test.

2.4. Tensile Strength Test

The tensile test (tensile test) is a static mechanical test by means of which the sample is pulled by loading at both ends where the tensile force exerted is P (Newton). The aim is to determine the tensile mechanical properties (tensile strength) of the tested composites[20]. In this study, tensile testing was carried out using the ASTM D638-14 type 1 method[21]. Prior to testing, the samples were conditioned at 23°C and 50% RH for more than 40 hours. The grip distance used was 115 mm, the sample was pulled at a speed of 5 mm/minute and the test room conditions had a temperature of 23.1°C and humidity of 59.6 RH. The tool used for the tensile test is the Shimadzu AG-X Plus 50 kN Universal Testing Machine.

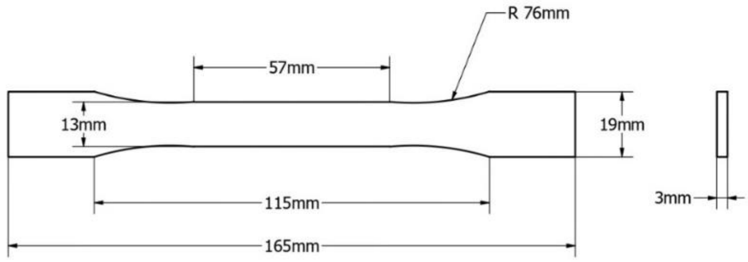


Fig. 1. ASTM D-638-14 Type 1 Standard Tensile Test Sample [22].

Tensile testing aims to determine the maximum tensile strength, strain, and modulus of elasticity by pulling the specimen until it breaks. Pressure and tension when forming samples for vehicle applications cause damage so it is necessary to test the maximum tensile strength, strain and modulus of elasticity. Tensile strength testing is carried out by making specimens adapted to the tensile testing standards ASTM D-638-14 "Standard Test Method for Tensile Properties of Plastics". The dimensions of the specimens used in this tensile test are type 1. Based on the results of the tests that have been carried out, data on the maximum tensile strength, strain and tensile modulus of the epoxy bamboo *Betung* fiber composite against variations in $KMnO_4$ concentrations of 3%, 5%, and 7%.

To calculate the amount of maximum tensile strength or Ultimate Tensile Strength is as follows:

$$\sigma = \frac{P}{A} \qquad \text{.................(1)}$$

International Journal of Engineering and Applied Technology (IJEAT)
Vol. 5., No. 2, November 2022, pp. 36-44

where σ is the tensile strength (kg/mm^2), P is a force (kg), A = cross-sectional area (mm^2) = width x thickness. [9]. While the formula for calculating Tensile Strain is as follows:

$$\varepsilon = \frac{\Delta L}{Lo} x\ 100\% \qquad \ldots\ldots\ldots\ldots\ldots..(2)$$

whereε is the tensile strain (%), ΔL is the increase in length (mm), and Lo is the initial length (mm) [9]. while the formula for calculating the modulus of elasticity (young modulus) is:

$$E = \frac{\sigma}{\varepsilon} \qquad \ldots\ldots\ldots\ldots\ldots..(3)$$

where E is the elastic modulus (GPa), σ is stress (MPa), and ε is strain (%) [23].

3. Data Analysis and Discussion

3.1. Test result.

In this tensile test, the data generated after testing is in the form of a graph of stress, strain, and modulus of elasticity, as well as the results of the fracture pattern of the composite. The results obtained from the graphical analysis of the tensile test at each variation in $KMnO_4$ levels can be seen in Table 1, and from Figure 2 to Figure 6.

Table 1. Composite Mechanical Properties Tensile Test Results

Sample Specimen	Force (N)	Elastic modulus (MPa)	Tensile Strength (MPa)	Strain ε (%)
0% $KMnO_4$	1375	10,60	28,06	2,645
3% $KMnO_4$	2208	19,38	33,24	1,715
5% $KMnO_4$	1858	15,36	33,55	2,183
7% $KMnO_4$	1713	20,84	31,54	1,513

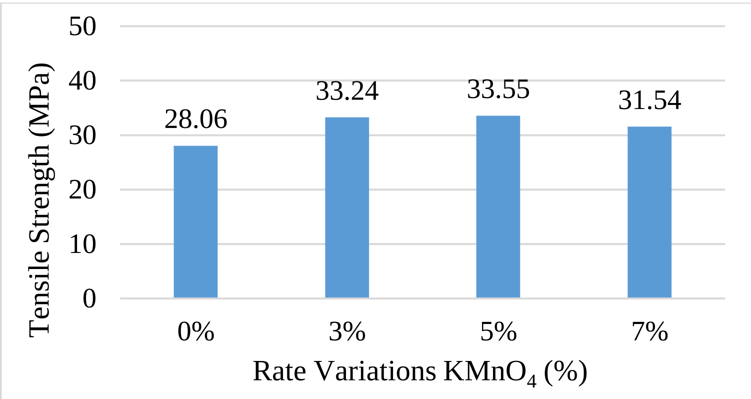


Fig. 2. Tensile Strength from permanganate concentration variations

Based on Figure 2 above, it can be seen that the highest tensile strength is at 5% $KMnO_4$ with a value of 33.55 MPa, this strength is affected by the addition of the percentage of $KMnO_4$ treatment to the maximum limit of 5% which can increase tensile strength. The epoxy *Betung* bamboo fiber composite treated with 5% $KMnO_4$ had the highest strength compared to the epoxy bamboo *Betung* fiber composite with 3% and 7% $KMnO_4$ content and without $KMnO_4$ treatment, while the lowest was the epoxy bamboo *Betung* composite without $KMnO_4$ treatment of 28. 06 MPa.

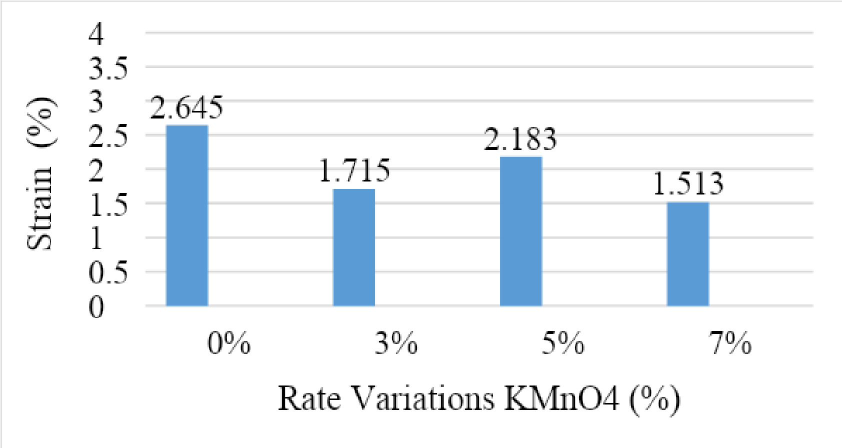


Fig. 3. Tensile Strain from different permanganate variations

Based on Figure 3 above, it can be seen that the strain value increased at 0% $KMnO_4$ content and decreased at 3%, 5%, and 7% KMnO4 content. The highest strain value was found at 0% $KMnO_4$ content with a value of 2.645%, but at 3% $KMnO_4$ level, 5%, and 7% decreased and even increased strain did not exceed 0% $KMnO_4$ levels. This proves that there is an effect of alkalization treatment on $KMnO_4$ levels on *Betung* bamboo fiber, and the smallest strain value is at 7% $KMnO_4$ content with a value of 1.513%.

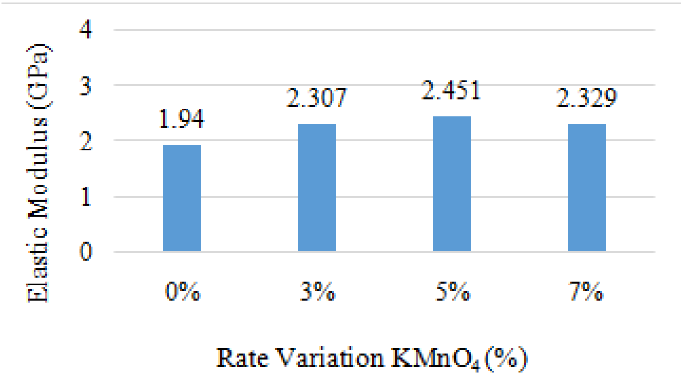


Fig. 4. Elastic Modulus from the different concentration of permanganate treatment

Based on Figure 4 above, the value of the elastic modulus, without treatment had the lowest modulus of elasticity, namely 1.94 GPa, whereas with 3% KMnO4 treatment it increased to 2.307 GPa. The addition of KMnO4 to 5% had the highest modulus of elasticity, namely 2.451 GPa, however, when the KMnO4 7% was treated, the modulus of elasticity decreased to 2.329 GPa.

International Journal of Engineering and Applied Technology (IJEAT)
Vol. 5., No. 2, November 2022, pp. 36-44

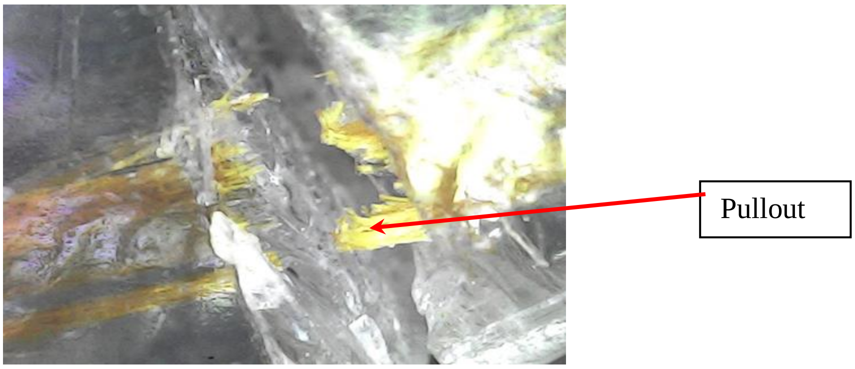
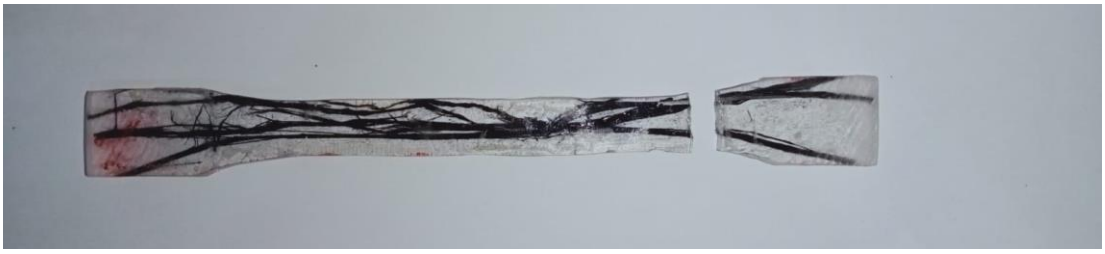


Fig. 5. Fault Pattern (Without $KMnO_4$ Levels)

Based on Figure 5 above, it shows the fracture pattern of the composite tensile test specimen without $KMnO_4$ levels, showing that the fracture is still caused by a pullout.



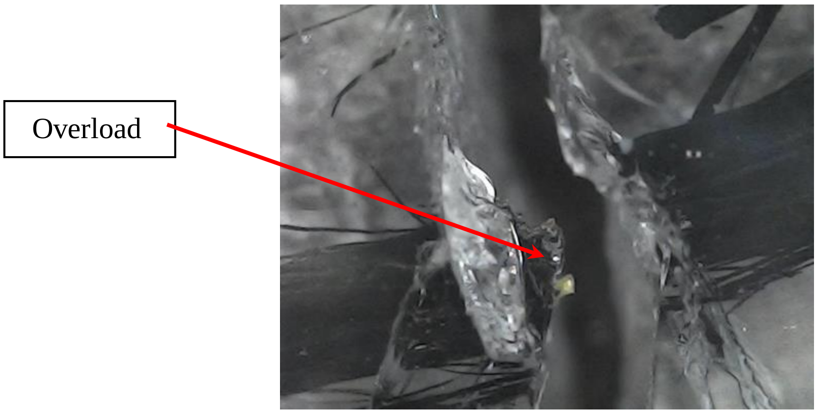


Fig. 6. Fault Pattern (rate $KMnO_4$)

Based on Figure 6 above, it shows the fracture pattern of the composite tensile test specimen with 5% $KMnO_4$ levels indicating the fracture was caused by overload.

3.2. Discussion

From Figure 2 the tensile strength test results obtained the highest value at 5% $KMnO_4$ with a value of 33.55 MPa, this tensile strength is affected by the addition of the percentage of $KMnO_4$ treatment up to 5% which can increase tensile strength. The 5% $KMnO_4$ treatment had the highest tensile strength compared to the 3% $KMnO_4$, 7% $KMnO_4$ and without $KMnO_4$ treatment, while the lowest was the *Betung* bamboo composite without $KMnO_4$ treatment of 28.06 MPa.

In the composite reinforced with *Betung* bamboo fiber with 5% $KMnO_4$ content, the highest tensile strength value was obtained with a value of 33.55 MPa. This was because it was affected after the $KMnO_4$ treatment was carried out to a maximum limit of 5%, causing a change in the interface between the fiber and the good matrix. Because the strength of the composite is a combination of the strength of the matrix and the fiber, it will depend on the nature of the interface, the better the bond between the fiber and the matrix. The tensile load given to the composite will be well distributed to the fiber, and vice versa if the fiber and matrix interface is less stronger than the tensile load is only held by the matrix [24].

In composites reinforced with bamboo *Betung* fiber without $KMnO_4$ treatment, it produced the lowest tensile strength value with a value of 28.06 MPa. This was due to poor fiber and matrix bonding. So that the interface properties of the *Betung* bamboo fiber composite without $KMnO_4$ treatment are not good, it is hindered by the presence of a layer that resembles wax or commonly called lignin on the surface of the fiber, so that when the tensile test is tested the failure is dominated by the release of the bond between the fiber and the matrix caused by shear stress on the surface. fiber which is called by the term "fiber pull out". In this failure condition, the matrix and fiber are actually still able to withstand greater loads and stretches, but because the bond between the fibers and matrix fails, the composite fails earlier [25].

The composite with 7% $KMnO_4$ yielded a tensile strength of 31.54 MPa, but the tensile strength decreased compared to 5% $KMnO_4$. This is due to the complete loss of $KMnO_4$ 7% hemicellulose, lignin and pectin, the strength of natural fibers will decrease because the microfibrils that make up the fiber which are joined together by lignin and pectin will separate, so that the fibers are only fine fibers separated from each other. The fiber becomes a little brittle so that the strength properties of the interface between the fiber and the matrix are not good, so that the amount of strain and stress that the composite can withstand decreases. Therefore, the increase in interfacial strength will be optimum when adding a certain $KMnO_4$ solution, in this study, which is 5% $KMnO_4$ [26]. One of the functions of lignin is as a reinforcement in wood fiber. So, when all the lignin in the wood fiber is lost, it can reduce the stiffness of a material [27].

Figure 5 shows the fracture pattern of the composite tensile test specimen without $KMnO_4$ content, showing that the fracture is still caused by a pullout which is caused because the bond between the fiber and the matrix is not strong [28]. The fiber is released from the matrix bond, so that when tested the tensile strength failure is dominated by the release of the bond between the fiber and the matrix caused by the shear stress. The surface of the fiber is then referred to as "Fiber Pull Out". In this failure condition, the matrix and fiber are actually still able to withstand greater loads and stretches, but because the bond between the fibers and matrix fails, the composite fails earlier.

From Figure 6. it can be seen that the fracture pattern of the composite tensile test specimen with 5% $KMnO_4$ levels indicate the fracture was caused by overload. Namely the breaking of the fiber caused by the strength limit of the fiber and the strong bond between the fiber and the matrix. In this variation, it can be seen that the composite fracture is flat on the surface with a few fiber fibers. Because there is a change at the interface between the fiber and the good matrix.

4. Conclusion

In terms of tensile strength, the highest tensile strength results were found in specimens with 5% $KMnO_4$ content, namely 33.55 MPa and the lowest in specimens without $KMnO_4$ content, namely 28.06 MPa. Meanwhile, the strain values obtained were the highest in specimens without $KMnO_4$ content, namely 2.645% and the lowest in specimens with $KMnO_4$ content of 7%, namely 1.513%. The value of the elastic modulus was obtained with the highest modulus of elasticity in the specimen with 7% $KMnO_4$ content, which was 20.84 MPa and the lowest in the specimen without $KMnO_4$ content, which was 10.6 MPa. In the tensile test specimen without $KMnO_4$ content there is a pullout fracture pattern, and in the tensile test specimen with 5% $KMnO_4$ content there is an overload fracture pattern.

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