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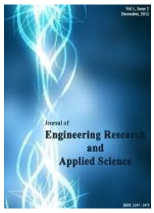

Tensile Strength Enhancement of an Epoxy System By SiO_2 Addition

M. Kerim Erarslan[1], Levent Semiz[1,2,*]

[1]Amasya University, Graduate School of Natural and Applied Sciences, Mechanical Engineering, Amasya, Turkey

[2]Amasya University, Vocational School of Technical Sciences, Chemistry and Chemical Process Technology, Amasya, Turkey

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Abstract

In this study, the tensile strength enhancement of an epoxy system was aimed by the addition of SiO_2 nanoparticles. Two main features of the nanoparticle performance on the tensile strength increment were particle size and particle amount. Hence, two particle sizes with various amounts were utilized for SiO_2 application in order to improve the tensile strength of the epoxy system. 80 nm particle sized SiO_2 provided 66.6% increment when the utilized SiO_2 amount was 0.5% by weight. Moreover, when particle size of SiO_2 was decreased to 5-20nm, the highest improvement was measured as 88.2%. Also, it was observed that there was a threshold in the utilization amount. Before this point the enhancement improved with SiO_2 amount. However after this point, the tensile strength started to decrease with increasing SiO_2 addition. This threshold was observed as 0.5% for both 5-20 nm and 80 nm particle sizes.

1. Introduction

In industry, epoxies have been utilized extensively due to their electrically insulating, chemically resistant, thermally stable and high mechanical features [1]. The most demanded property of epoxies in structural utilizations is the mechanical strength [2]. Various studies have been conducted in order to enhance this feature. Basically, they can be divided in two groups. One is the synthesis of new epoxy structures having different chemical compositions that contain groups which can provide higher mechanical strength [3]. The other is the utilization of additives in epoxies [4]. The last one is way easier than synthesizing newer materials. The addition of an additive to the epoxy solution can enhance the interaction of the epoxy chains which increases the mechanical strength of the utilized epoxy. Moreover, the addition of additives also helps to reduce the crack formation during curing [5]. Since crack domains act as weak regions during mechanical stress, the breaking starts to occur within these regions. Thus, the amount of these regions dramatically decreases the mechanical strength of the epoxy.

Fibers [6–8], polymers [9, 10], metal oxides [11–13], graphene oxide [14], carbon [15], carbon nanotubes [16], gold [17], silica [18, 19] can be named among the utilized additives. Especially, SiO_2 has been widely used due to its enhancement capability of mechanical properties for polymer matrixes with their efficiency of stress transfer capability during fracture [20, 21]. Beside the additive type, additive features also affect the strength of the epoxy. Among the features, size and the amount of the additive are the simplest to control and most effective features. Thus, in this study, SiO_2 with two sizes of 5-20 nm and 80 nm were utilized in the range 0.1% to 4% (w/w) for the enhancement of the mechanical strength of the epoxy in order to obtain highest possible tensile strength increment for the epoxy system and their effects on the increment rate were analyzed.

*Corresponding author:levent.semiz@amasya.edu.tr

2. Experimental

The two component epoxy system (Epo 300) was purchased from Demarin. The SiO_2 particles having particle sizes of 5-20 nm and 80 nm were obtained from Sigma and Alfa Aesar, respectively.

In order to find the best epoxy/hardener ratio, the ratio was varied from 1/1 to 2.5/1. They were mixed with magnetic stirrer and poured to molds and left for curing at room temperature for at least five days to ensure the complete curing. The obtained specimen had dimensions of 30 mm width, 50 mm length and 3 mm thickness.

For SiO_2 addition to the epoxy system, the following procedure was applied. SiO_2 was first added to the epoxy and stirred with magnetic stirrer. Then, the solution was sonicated for the achievement of better dispersion of SiO_2 particles in the epoxy structure. After the dispersion of particles, hardener was added to epoxy-SiO_2 solution while stirring. Then, the casting procedure was applied.

The tensile tests were conducted via Alşa test machine (Fig. 1) with a displacement rate of 10 mm min^{-1}. The length of the epoxy between the jaws was adjusted as 40 mm.

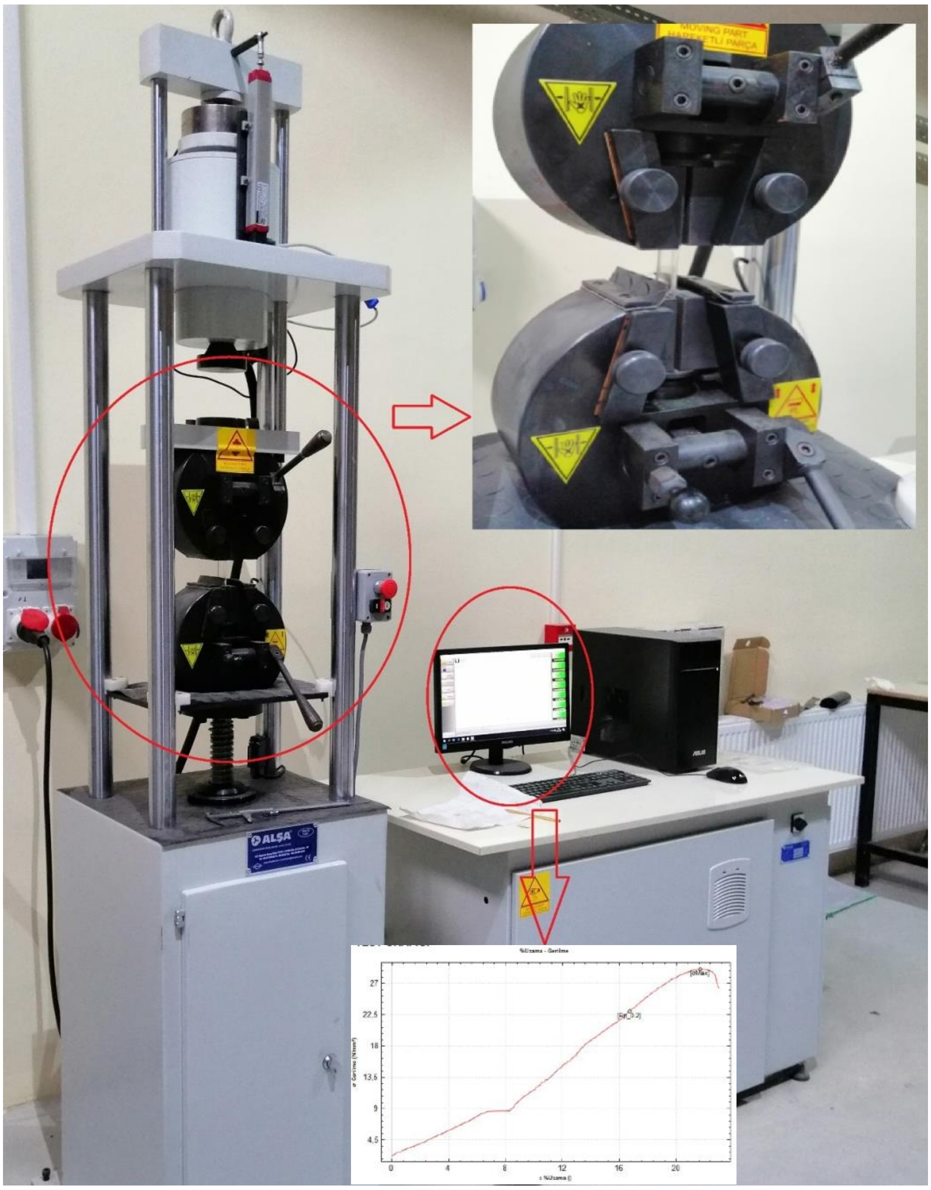

Figure 1. Tensile test setup

3. Results and Discussion

It was well known that the epoxy/hardener ratio was the basic effect on the effectiveness and the strength of the epoxy. Thus, first of all, the optimum ratio that gave the maximum tensile strength should be found. In order to this, epoxy/hardener ratio (V/V) was altered from 1/1 to 2.5/1. Although the term "hardener" was used for the crosslinking agent in the epoxy, higher amount of hardener may not give higher tensile strength. As can be seen in Fig. 2, the tensile strength of the specimen increased as the epoxy hardener ratio was increased to 2/1. After this point, the increase in the ratio led to negative effect on the tensile strength. Moreover, since polymers generally did not demonstrate linear behaviors in tensile tests, the increase and decrease in the tensile strength were not linear also. Thus, it was hard to calculate the tensile strength by using a formulation including the epoxy/hardener ratio. As 2/1 found to be the best ratio that provided the highest tensile strength, this ratio was utilized for further experiments.

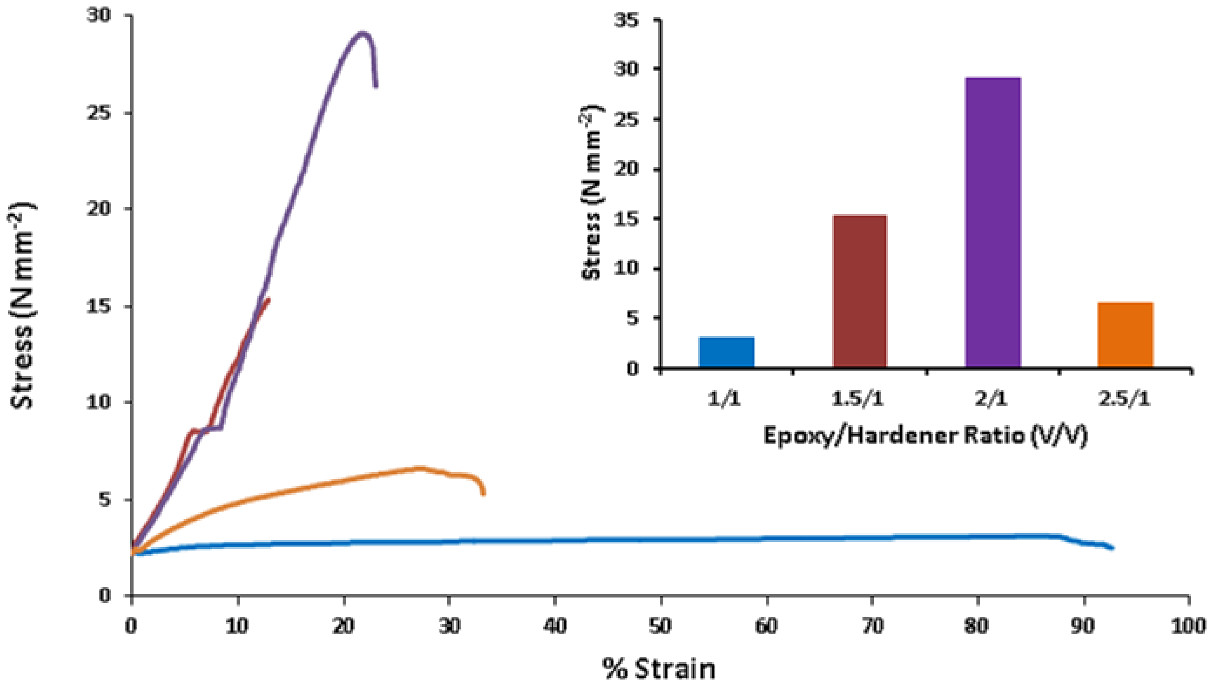

Figure 2. The effect of epoxy/hardener ratio on the tensile strength

Addition of additives to the epoxy enhanced the tensile strength by decreasing the microcracking formation during curing period and increasing the interaction of polymer chains by acting as crosslinking point and providing surface. Thus, the size and amount of the additive were the two main parameters that affect the tensile strength of the epoxy system. The increase in amount provided more crosslinking points and more surfaces. Also, decrease in the particle size led to higher surface area per weight of additive. Moreover, as the size decreased to nanometer scale, the charge interactions, even London forces, became important effects. Hence, the amount and the size of the additive were two important parameters for the enhancement of epoxy strength. However, these effects may not be on the same order as the size of the additive changes. Therefore, the optimum values should be found as the additive particle size was altered.

A set of various weight % of 80 nm SiO_2 was prepared in order to find the optimum additive amount for this size. The amount of the additive increased from 0.25% to 4%. As can be seen in Fig. 3, when the additive was used at 0.25%, the tensile strength showed enhancement when compared to non-additive utilized counterpart and increased from 29.1 to 38.3 N mm^{-2}. Also, when the additive amount was further increased, the tensile strength also displayed increment and was found as 48.5 for 0.5% SiO_2. The tensile strength showed enhancement with additive amount. Also, this increase in the tensile strength with the additive amount did not go on continuously. As can be demonstrated in Fig. 3, the highest tensile strength was found when the additive was utilized as 0.5%. Further increase in the amount affected the epoxy system negatively and decreased the tensile strength. It was measured as 44.3, 38.5 and 36.7 N mm^{-2} for 1%, 2% and 4% SiO_2, respectively. However, these values were also higher than the non-additive utilized specimen. Since it was aimed to obtain the highest tensile strength, 0.5% was found to be the optimum additive amount for 80 nm.

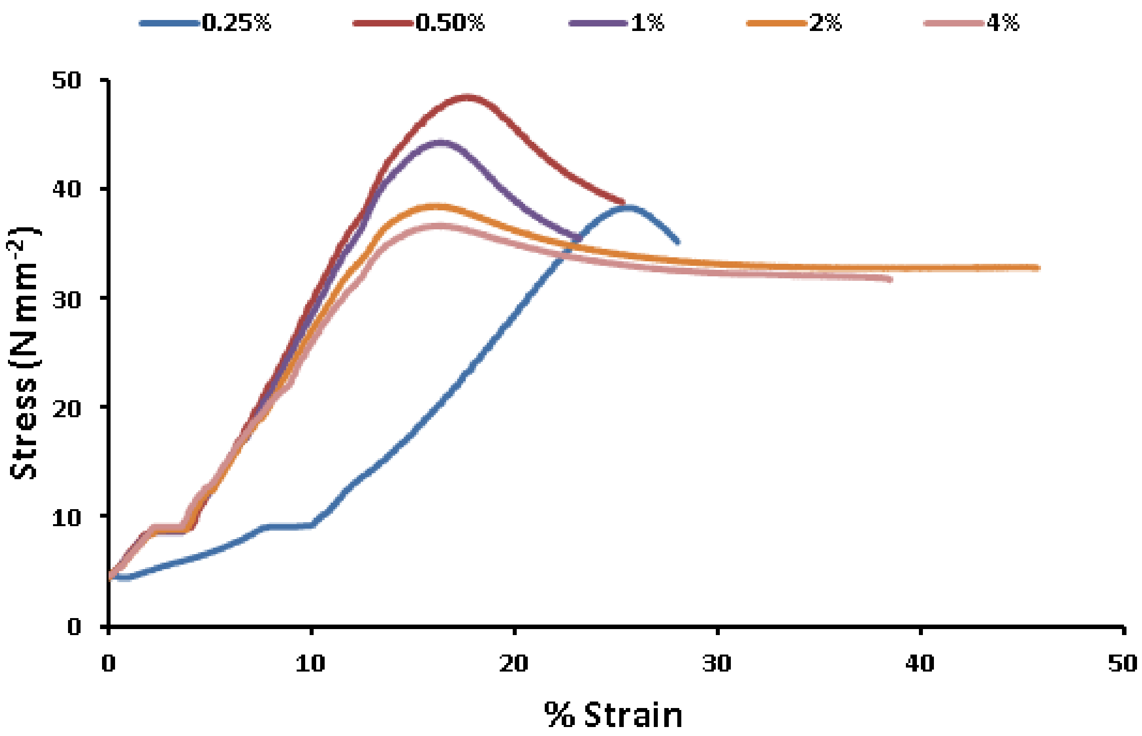

Figure 3. Stress vs strain for different SiO_2% for 80 nm

When the particle size decreased to 5-20 nm level, the enhancement of the tensile strength was observed more obvious. SiO_2 nanoparticles of 5-20 nm enhanced the tensile strength of the epoxy system and increased it to 51.2 N mm^{-2} when it was utilized as 0.1% (Fig. 4). This value was much higher when compared to the highest value of 0.5% SiO_2 with 80 nm particle size. The decrease in particle size with lower additive amount in weight provided more improvement in the tensile strength. However, this value may not be the highest one for 5-20 nm SiO_2. Thus, in order to determine the highest tensile strength for the epoxy system doped with 5-20 nmSiO_2 nanoparticles, the amount of nanoparticles was increased till the decrease in tensile strength was observed. As the nanoparticle amount increased to 0.5%, the tensile strength was observed as 54.7 N mm^{-2}. However, further increase in the amount demonstrated negative effect on the tensile strength of the epoxy system. When the amount was increased to 0.75%, the tensile strength started to decrease. It was measured as 53.8 N mm^{-2} when SiO_2 nanoparticles used as 0.75%. On the other hand, this value was still higher than the highest tensile strengths of both the undoped and 80 nm SiO_2 doped epoxy systems. As a result, it was found that the decrease in the particle size provided higher optimum tensile strength enhancement for the epoxy system and the highest tensile strength was measured as 54.7 N mm^{-2} when 5-20 nmSiO_2 nanoparticles was utilized at 0.5%.

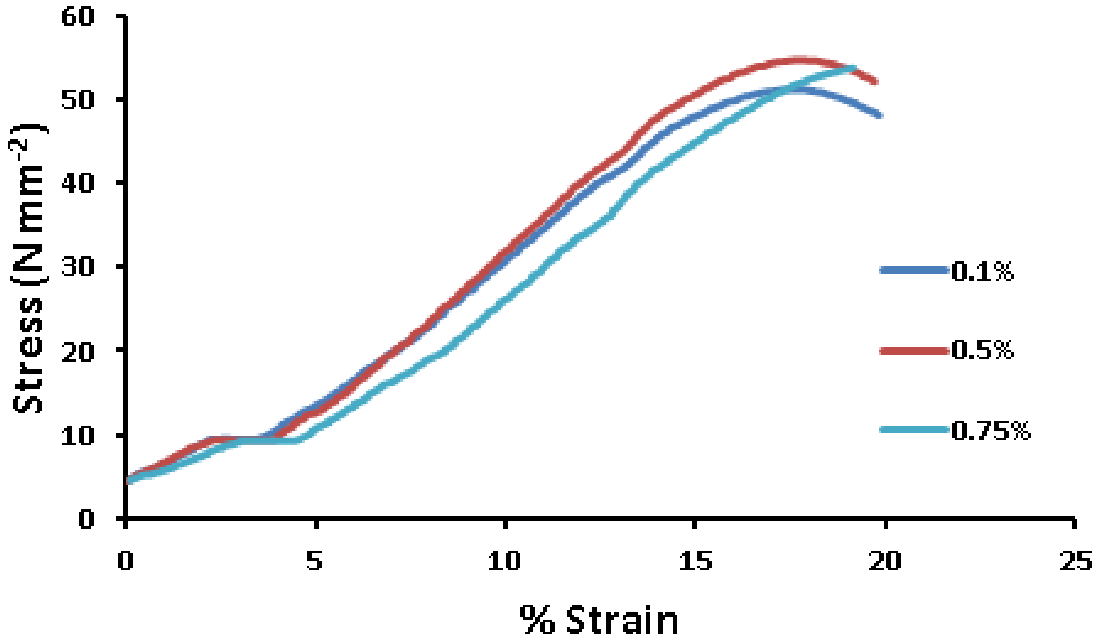

Figure 4. Stress vs strain for different SiO2% for 5-20 nm

The % enhancement of the tensile strength after doping of the epoxy system with 80nm and 5-20 nm particle sized SiO_2 is demonstrated in Fig. 5. As can be seen from the enhancements, the 80 nm particle sized SiO_2 provided 31.6% tensile strength increment when it was utilized at 0.25% in the epoxy system. As the amount was increased, the % tensile strength increment went up to 66.6% that is the highest enhancement ratio obtained when the utilized SiO_2 was 0.5%. After this point, the enhancement decreased when compared to previous value but the values were still higher than the undoped epoxy system's tensile strength. The corresponding tensile strength improvement values for 1%, 2%, and 4% SiO_2 were 52.3%, 32.3 %, and 26.1%, respectively. Moreover, when the particle size decreased to 5-20 nm, the tensile strength enhancement values for 0.1%, 0.5%, and 0.75% SiO_2 were calculated as 76.1%, 88.2%, and 84.8%, respectively. As can be seen, the highest value was obtained with 0.5% SiO_2 doping for 5-20 nm particle size as like 80 nm particle size.

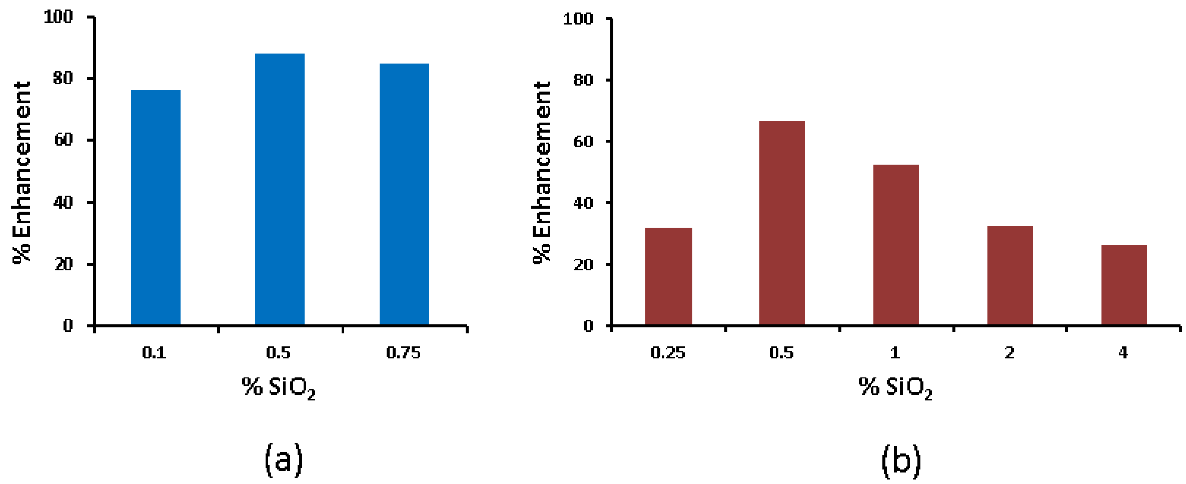

Figure 5. % Enhancement vs SiO_2% for 5-20nm (a) and 80 nm (b)

4. Conclusion

The results demonstrated that the addition of SiO_2 provided an enhancement in the tensile strength of the epoxy system. Moreover, the particle size and particle amount had crucial effect on the improvement rate. Decrease in the particle size led to higher tensile strengths. On the other hand, there was an optimum point for the utilization amount of the nanoparticles. Upto this point the enhancement increased with the nanoparticle amount. However, beyond this point, the tensile strength started to decrease. The highest increments were obtained with 0.5% SiO_2 utilization for both 5-20 nm and 80 nm particle sizes. The highest enhancement rates were measured as 66.6% and 88.2% for 5-20 nm and 80 nm particle sizes, respectively. According to the results, the addition of nanoparticle could enhance the tensile strengths of epoxy systems which could be defined as a function of particle size and particle amount.

Acknowledgments

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