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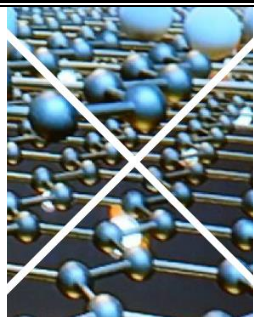

EFFECT OF NANO SILICA WITH EPOXY RESIN BONDED SINGLE-STRAP REPAIRS

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Abstract

In this study, the effects of tensile properties of epoxy adhesive with nano-silica on the glass epoxy laminates adhesively bonded single strap repairs are investigated. Nano-silica particles were added to the epoxy resin with an amount of 1, 2, 3 wt%. Single strap repairs were used as different patch ratio (D/d=2, and D/d= 3). Patches were opened by a CNC machine having a 10 mm diameter. Tensile tests were carried out on the specimens and their load carrying capacities were measured. Experiments show that load carries capacity increases with increasing nano-silica in epoxy.

Keywords: adhesively bonded, silica, single-strap repairs.

1. Introduction

In recent years, composite materials have been thoroughly using in engineering application areas such as electronics, aerospace, aeronautics, automotive, and traditional industries such as sports, packaging, and construction. The application of composites has been widely increasing due to the development of new fibers such as carbon, boron, and aramids, and new composite systems with matrices made of metals and ceramics since the 1970s. Adhesively bonded repairs are rising options to mechanical repairs in engineering application areas and ensure many advantages over conventional mechanical connectors. These advantages are lower edge stress concentration factors, a more uniform distribution of stress, lighter weight, water tightness, and better fatigue properties, lower fabrication cost, etc. [1-4].

Commonly used methods to adhesive bonds damaged the structures consist of single or double lap/strap, scarf, and step configurations. (Schematic representation of single-strap, double-strap, and scarf repairs are shown in figure 1). Single and double-strap repairs put forward the advantages of easy application and low costs. However, they may not be viable for high responsibility structures because these geometries lead to moderate peel and shear stress concentrations at the bond edges, appearing from the different straining effects on the structure and patches, which obstruct a high efficiency of these repairs.[5-6]

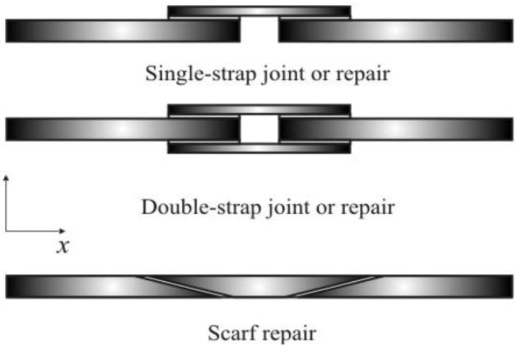


Figure 1. Schematic view of single-strap, double-strap, and scarf repairs.

Many authors have studied the mechanical properties of composite materials on the adhesively-bonded repair techniques. Moreira et.al [7] studied high-cycle fatigue analysis of single-strap repairs of carbon–epoxy composite laminates. It was concluded that cohesive failure inside the adhesive revealed higher fatigue life relative to the interlaminar failure of the adherend and applied load is the most important parameter influencing the fatigue life. Campilho et. al [8] studied an experimental and finite element parametric on the behavior of single and double-strap repairs of carbon-epoxy laminates under buckling unrestrained compression. It was concluded that the finite element method might be a valuable predictive tool and an option for the reduction of costs due to experimentation, provided that suitable criteria are employed for the simulation of the different types of fracture. De Moura [9] researched the application of cohesive zone modeling to composite bonded repairs. It was concluded that the best combination of the geometrical effects analyzed consists of a combination of patch inner chamfering and 45° straight fillet. Bulut et. al [10] studied the tensile properties of epoxy adhesive with the inclusion of micro-scale perlite and sewage sludge ash particles for glass-epoxy laminates adhesively bonded single-strap repairs. It was found that the joining performance of composite laminates can be improved by the mixing of perlite or SSA filler with an adhesive epoxy at a low weight percentage of both fillers contributing to resolving an important engineering problem during the service. Çitil [11] investigated the effects of patch material on the adhesive in the repair of damaged pipes. Pattanaik et. al [12] investigated the effect of mixing time on the mechanical properties of fly ash-filled epoxy-based composites, which showed that the importance of suitable mixing between adhesive and filling particles. Daraker and Chandore [13] studied the effect of surface roughness on single lap adhesive joint strength. It was found the surface roughness parameter must be considered during the design stage of adhesively bonded joints, as the bond strength varied significantly by 30–35 %, between the different surface roughness values. Cheng et. al [14] investigated that analysis of an adhesively bonded single-strap joint integrated with shape memory alloy (SMA) reinforced layers. It was concluded from the numerical analyses that the SMA provides an effective way of enhancing the load-carrying capacity of composite joints. Tsai et.al [15] investigated the stresses in double-lap adhesive joints with laminated composite adherents. Experimental and finite elements showed that the displacement fields are obtained from both analyses, respectively, for both joints, except for a fringe waviness, due to the three-dimensional phenomena.

There are no studies related to the investigation effect of nanoparticles on the adhesive of patches in the open literature. The purpose of this study was to investigate the load-carrying capacity of a single strap joint of S-glass/epoxy composite reinforced with nano-silica particles. Nano silica particles were added to the epoxy resin with an amount of 1, 2, 3 wt%. The load-carrying capacity of samples was explored in terms of force-displacement relation and results were compared with each other for different patch ratios (D/d=2, and D/d= 3).

2. Materials and Procedures

2.1. Production of test examples

The composite plates have been used in the experiments where the density of glass fiber is 200 g/m^2. An epoxy resin (Momentive-MGS L285) with hardener (Momentive-MGS H285) at a stoichiometric ratio of 100:40 was used as the matrix. The main mechanical properties of both epoxy and S-glass fiber are listed in table 1 and table 2.

The composite plates were cut to using a CNC machine. The size of the composite plates was 100 x 50 mm. The Centre of the composite plates was drilled with a 10 mm diameter in a CNC machine, which yielded the patch repair ratio D/d=2, and D/d=3 (patch diameter (D), and hole diameter(d)). Patch diameters used for patch ratios were 20 and 30 mm, the average thickness of the samples was measured as 2 ± 0.2 mm, and the adhesive thickness of the adhesive layer is measured as 0.2 mm.

Table 1 Mechanical properties of epoxy [16].

Density (g/cm³)	1.18-1.20
Flexural strength (N/mm²)	110-120
Modulus of elasticity (N/mm²)	3.0-3.3
Tensile strength (N/mm²)	70-80

Table 2 Mechanical properties of S-glass fiber [17].

E_{12}	19.6 GPa	υ_{12}	0.14	G_{12}	3.8 GPa
E_{21}	19.6 GPa	υ_{21}	0.08	G_{21}	3.8 GPa
E_{23}	11.7 GPa	υ_{23}	0.08	G_{23}	3.8 GPa

The sandpaper was used to smooth the surface of the composite plates and patches then cleaned with acetone before the bonding. Nano silica, hardener, and epoxy resin were stirred in different ratios at 12000 rpm for 5 minutes by the mixer.

Plates and patches were bonded with a mixture of nano-silica, hardener, and epoxy resin. The mixing ratio of nano-silica is given in table 3. The chemical composition and physical properties of the silica are shown in table 4.

Table 3 Weight ratio of nano-silica

Sample Name	silica (wt%)	Plates and patch (D/d=2)	D/d=3
NS-0	0	5	5
NS-1	1	5	5
NS-2	2	5	5
NS-3	3	5	5

Table 4 Chemical composition and physical properties of the silica [18].

Content	Nano Silica
SiO_2	99.05
Al_2O_3	0.05
Na_2O	0.48
LOI	0.10
Physical Properties	
Specific Gravity	1.37
Specific surface area (BET) m²/g	85

2.2. Tensile test

Tensile tests were performed on the controlled tensile test machine Shimadzu AG-X shown in figure 2**.** The machine worked with 300 kN at a crosshead speed of 1mm.min $^{-1}$. Five repeating test samples were used for each group, and their average results were taken.

Figure 2. Shimadzu AG-X Machine

3. Results and Discussions

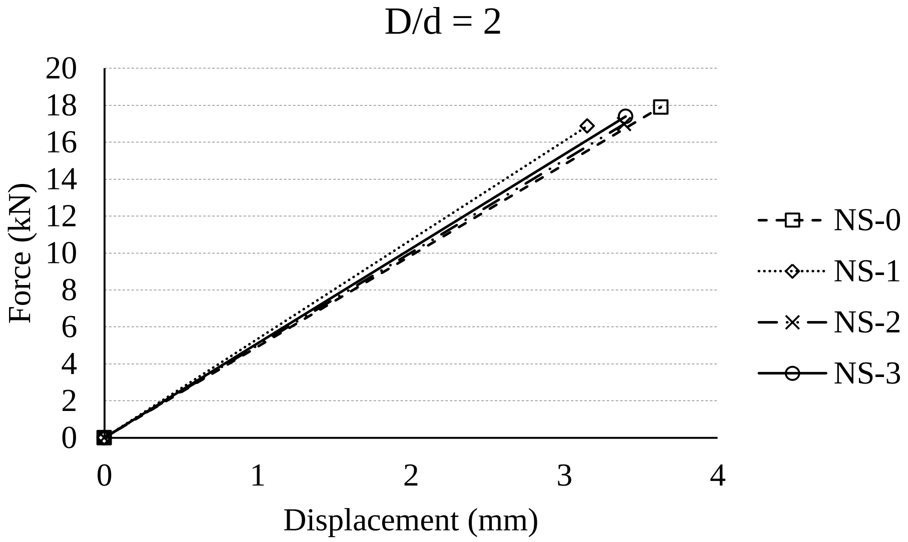
3.1 Effect of Nano Silica

Patch repairing performances of the samples were examined with two different patch repair ratios (D/d = 2 and D/d= 3). Tensile results were measured for four different mass ratios of the nano-silica particle by mixing adhesive epoxy. The results of the tensile tests are listed in table 5.

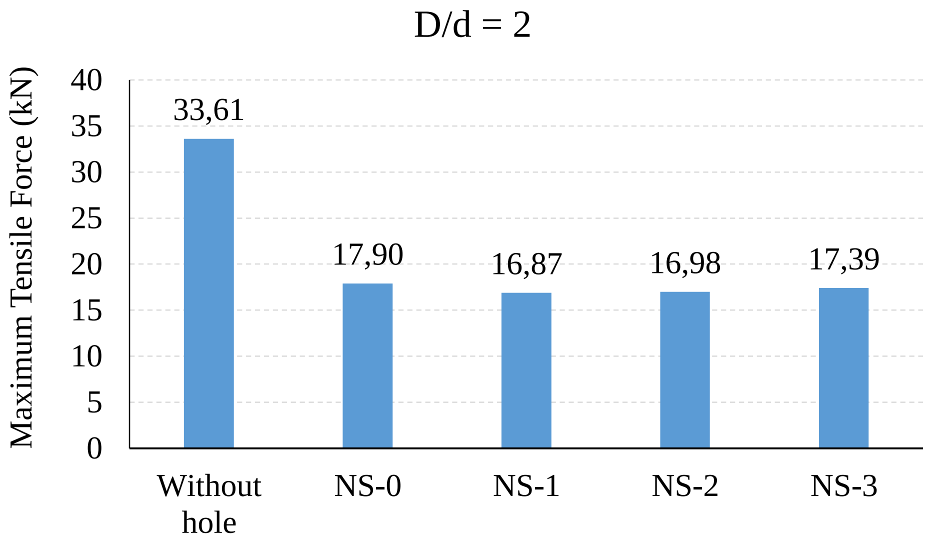
Table 5 Tensile test results are listed.

Sample (D/d=2)	Maximum Force (kN)	Displacement at break (mm)	Sample (D/d=3)	Maximum Force (kN)	Displacement at break (mm)
Without hole	33.61	6.06	Without hole	33.61	6.06
NS-0	17.90	3.63	NS-0	17.60	3.94
NS-1	16.87	3.15	NS-1	17.10	3.20
NS-2	16.98	3.39	NS-2	17.64	3.42
NS-3	17.39	3.40	NS-3	18.18	3.59

Force-displacement relations and their maximum values are shown in Figures 3 and 4 for different patch ratios. As can be seen from the result, drilling of the plate caused a significant decrease in the tensile force of the composite plate. When the composite plate was repaired with a patch having a nano-silica added epoxy adhesive, the tensile strength slightly increased. However, the amount of elongation in the tensile experiment has decreased because the epoxy turns into a more brittle structure. The tensile strength values of the samples with the patch ratio D/d = 2 were lower than those without silica. But tensile strength was higher in tests with patch ratio D/d = 3. As it is understood from the results, the effect of silica increases as the patch diameter increases, and tensile strength increases with an increasing amount of silica in epoxy. The maximum tensile force was increased by up to 3% wt of nano-silica. According to test results, the maximum single strap repair performance in tensile strength (3% wt content of silica particles) was recorded as 3.29% for *D*/*d* = 3 compared with the pure epoxy adhesive.

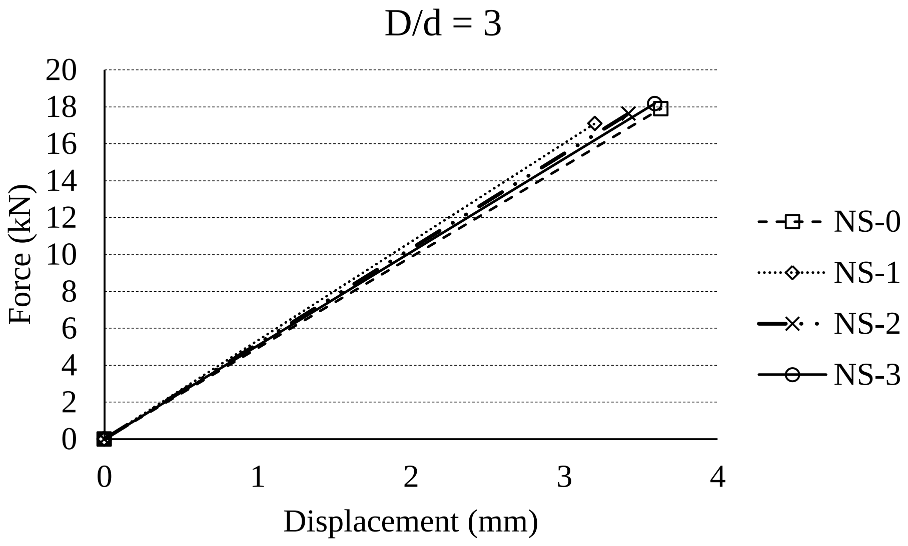


(a)

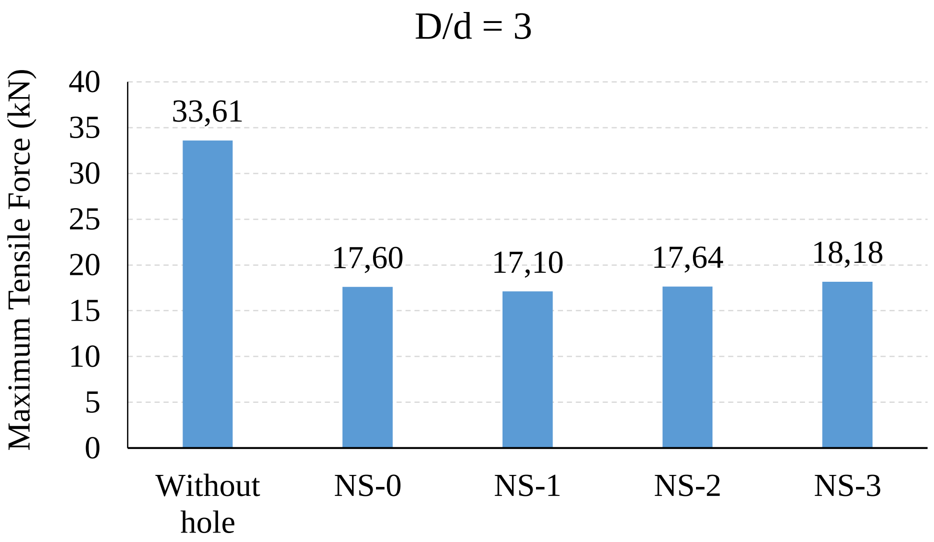


(b)

Figure 3 (a) Force-displacements (b) Maximum tensile force values for D/d = 2



(a)



(b)

Figure 4 (a) Force-displacements (b) Maximum tensile force values for D/d = 3

The particles remaining on the plates after the test are more visible when the patch diameter (D/d = 3) is large. This shows that the increase in the amount of silica added to the epoxy and the increase in patch diameter increases the tensile strength and indicates that the amount of holding has increased. This was also attributed to the distribution and weight percentages of particles in the epoxy, resulting in the higher strength between particle-matrix interfaces (shown in figure 5). However, opening a central hole resulted in the reduction of tensile strength by about 47.61%.

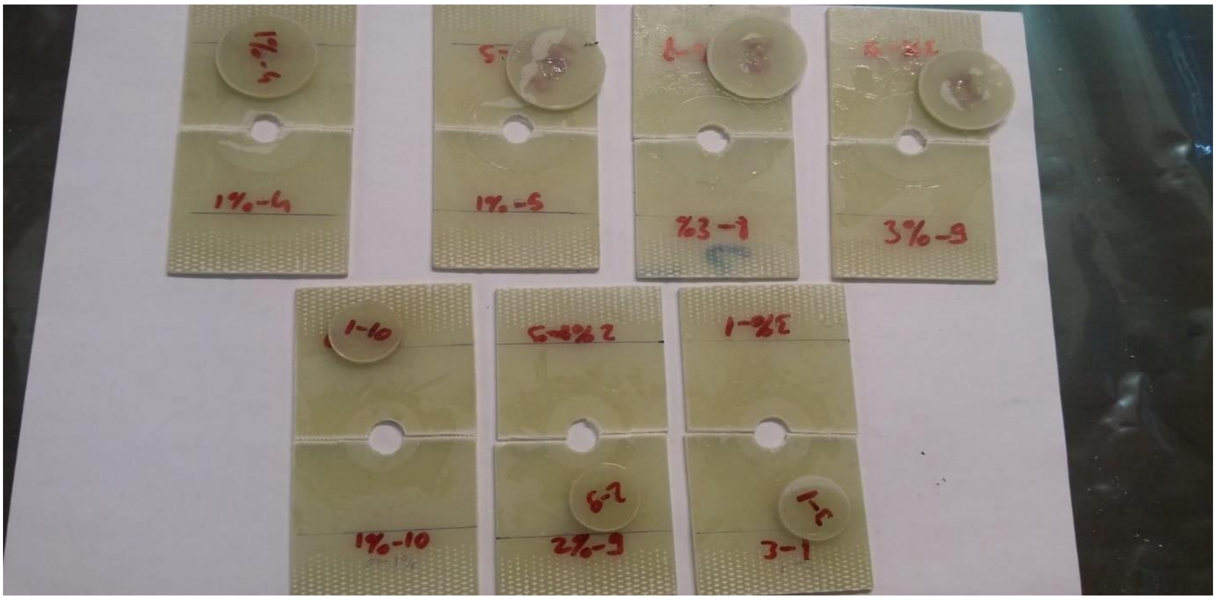


Figure 5. Fractured samples after tensile tests.

4. Conclusions

The effect of nano-silica particle inclusions on patch repairing performance of S-glass reinforced composite laminates was investigated by mixing within the adhesive epoxy resin with different contents. The following conclusions can be written from this study:

- A higher amount of nano-silica particle inclusion increases the tensile strength of patch repaired composite plates.
- Nano-silica content at 3 wt%, tensile strength reaches its maximum value due to the improvement of load transfer between particle-matrix interfaces.
- Patch repairing performance of the samples with *D*/*d* = 3 is greater than samples with *D*/*d* = 2.
- The maximum single strap repair performance in tensile strength (3% wt content of silica particles) was recorded as 3.29% for *D*/*d* = 3 compared with the pure epoxy adhesive.
- Particles remaining on the plates after testing became more visible when the patch diameter was large. This shows that the increase in the amount of nano-silica added to the epoxy adhesive and the increase in the diameter of the patch increases the tensile strength.
- As a result, repairing the performance of composite laminates can be improved by the mixing of nano-silica particles with an adhesive epoxy at a high weight percentage of particles, contributing to resolving an important engineering problem during the service.

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