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Overhauling of Steel Pipes Using Vacuum Bagging Processed CFRP Patch

*Syam Kumar Chokka, Beera Satish Ben
and Kowtha Venkata Sai Srinadh*

Abstract

The present work deals with the experimental study on rehabilitation of damaged steel pipes. The process of rehabilitation was done by using adhesive bonded CFRP patch on damaged sites of the pipes with the help of vacuum bagging set-up. The reference optimal parameters to rehabilitate the damaged pipes were considered from the tensile test (tensile shear load) conducted on plates. The rehabilitated pipes were tested under hydrostatic pressure. The two-component structural adhesive (Araldite AW105 and Hardener HV 953U) used in this study has high viscosity. It is not desirable for CFRP composite making and may lead to improper penetration of adhesive through open pores of the adherent surface. The viscosity of the adhesive was reduced in two ways: addition of a low viscous two-component nonstructural adhesive (Araldite LY-1564 and Aradur-22962) and heating the adhesive. Vacuum pressure, bond length and pre-bond surface preparation of the adherents were considered as parameters to evaluate the bond strength. The roughness of different samples was studied using a 3D microscope. The surface morphology of adherent was studied using scanning electron microscopy (SEM). Based on the experimental studies, it is observed that the optimal conditions of the tensile data of the plates hold good for the rehabilitated pipe under hydrostatic loading.

Keywords: vacuum bagging process, adhesive viscosity, surface pre-bond preparation, carbon fibre, SS-304 plates and pipes

1. Introduction

Fibre-reinforced polymer (FRP) composites are made of a polymer matrix reinforced with fibres. They are different types of fibres generally carbon, glass, aramid fibres, etc., while the polymers are generally an epoxy, polyesters, vinyl esters, etc. Polymer composites are used in automotive, marine, construction and aerospace industries. Carbon fibre-reinforced polymer (CFRP) composites have high strength to weight ratio and are resistant to most chemical attacks.

There is a huge demand for repairing or strengthening of existing structures in many applications either to sustain increased loads or to repair deteriorated structures. Many structural members like metallic pipelines, bridges and such other structures may deteriorate as they age, where the conventional method of repairing involves replacement or welding another plate over the damaged plate. The plates

used to rehabilitate the structure are usually heavy, the process is difficult and chances of corrosion and fatigue are high as they are subjected to high temperatures while welding. Adhesive bonded CFRP patch can be a good replacement for conventional methods as it has a high strength to weight ratio with design flexibility [1, 2]. Adhesive bonding can be done for similar, dissimilar and thin components. There are many applications in marine structures for adhesive bonding such as bonding of the hull to the deck, the channels running through the deck, the sea chests, engine compartment and the exhaust system. Repairing with CFRP patch can give a long life to the components as they have high resistance to chemical attacks and corrosion.

The cost of the structural repairing with adhesive bond using wet lay-up method can be reduced [3, 4]. In this process, fibre mats were wetted by an adhesive/resin until the desired thickness is achieved. Rollers are used to promote good impregnation of the fibre and reduce the voids entrapped in the adhesive mixture. The use of wet/hand lay-up results from the ease of application, minimal tooling cost and low cost of raw material. But the emissions from the adhesive/resin, low fibre volume fraction and high void content may limit its use [5–8]. The hand/wet lay-up process along with vacuum bag can prevent the harmful emissions and produce better quality products with the help of vacuum pressure.

Vacuum bagging process is used in many repairing applications in construction, marine and aerospace industries. Generally, scarf repair uses wet lay-up vacuum bagging process to bond CFRP patch on the surface of the damaged components. However, generally, the bond between the adherents is weaker than adherents in most cases due to the inability to apply sufficiently high-pressure during curing process. Thus, piles are added to the patch to attain the desired stiffness and load-carrying capacity [9]. The increased thickness of the patch enhances the bending stiffness and leads to premature failure at the edges under bending loads [10]. The properties of the repair patch can be enhanced by reducing the void content and increasing the fibre volume fraction which may be possible by vacuum bagging process.

Adhesive bonding can be done for similar, dissimilar and thin components. But the problem with adhesive bonding of metal plates with CFRP is its low strength. The major adhesion mechanisms that occur between CFRP and metals are (a) chemical bonding such as van der Waals forces, (b) mechanical interlocking between adhesive and substrate and (c) diffusion bonding. Joint strength for interdiffusion phenomena depends on diverse aspects, namely, contact temperature, time, nature and molecular weight of the polymers, etc. In order to vary the mechanical interlocking of surfaces, pre-bond surface preparation is needed, which includes surface abrasion, sand blasting, etching, etc. [11]. Mechanical interlocking is provided by allowing adhesive to wet the cavities and asperities of adherent surface. However, the surface asperity dimension should be controlled to avoid the formation of air bubbles. Air bubbles can generate regions of stress concentrations which are not desirable. In most cases, rough surface is good for better mechanical interlocking between the adhesive and adherent.

The evaporation of resin is another source of void formation in composites. The evaporation was high at the beginning of curing at room temperature. After 30 min, the evaporation settles to a constant rate. The high evaporation speed at the beginning was probably caused by air dissolving in the resin. The air bubbles can be removed with the application of vacuum to the mould [12, 13]. The application of vacuum pressure may pull the air bubbles formed during the process out of the mould. If the vacuum pressure is too high, the carbon fibre preform arrests the air bubbles formed between the laminates and creates voids [14]. The increased vacuum pressure may increase the compaction pressure on the carbon fibre preform which in turn reduces the resin content in the final product.

To rehabilitate the damaged SS pipe using a composite patch (CFRP) prepared with vacuum bagging process, the important aspect to study is the bond interface between SS and CFRP [15]. Single-strap adhesive joint is the least strength joint configuration than any others [16]. The present work aims to enhance the adhesive bond strength (tensile shear load capacity) of single-strap SS-CFRP joint using vacuum bagging process. The parameters for investigating the effect on load capacity of the joint are adhesive combination and temperature, vacuum pressure, bond length and surface of the adherent with different surface textures. These optimal parameters are applied to rehabilitate the damaged SS pipes and investigate its hydrostatic pressure resistance.

2. Materials and methods

2.1 Materials

Major materials used for the current study along with their properties were given in **Table 1**. The properties of the adhesives were taken from the Huntsman Advanced Materials, Switzerland data sheet. Fibre properties were considered from the Toray Composite Materials America, Inc. data sheet. Along with major materials, consumable like ferric chloride, distilled water, sticker tape, vacuum bagging, etc. were also used.

S. no	Materials		Viscosity [Pa s]	Tensile strength [MPa]	Elastic modulus [GPa]	Density at 25°C [g/ cc]
1	Structural adhesive (10:8 mix ratio)	Araldite-AW 106	30–50	Not given	Not given	1.14–1.15
		Hardener- HV 953 U	20–35			0.94–0.95
2	Nonstructural adhesive (10:2.5 mix ratio)	Araldite LY 1564	1.2–1.4	75–80	2.8–3.3	1.10–1.20
		Aradur-22962	0.005–0.02			0.89–0.90
3	Fibre	12KUD- 300 Gsm UD-carbon fibre	NA	3500	230	1.76
4	Stainless steel	SS 304	NA	550	200	7.85

Table 1.
Materials and properties.

2.2 SS plate preparation

SS plates were considered in the following dimensions: 125 × 25 × 3 mm. The surface of the samples was prepared with different surface preparation methods. The surface preparation includes surface without preparation cleaned with acetone (plane surface), surface prepared with etching, surface prepared with sand blasting and the sandblasted surface with open surface cavities.

The open surface cavities were made on the SS plates using chemical etching process. To perform chemical etching on the samples, the part of material to be etched should be opened to the chemical interaction, and the rest of the material was

masked with sticker tape. Ferric chloride and distilled water were mixed in the ration of 1.5:10. The masked samples were dipped and rinsed in the etchant (ferric chloride and distilled water mixer) for 8 min to get 80 ± 0.1 -micron deep surface cavities. The etching process and the etched 3D microscopic image were shown in **Figure 1a**. The pipe surface was also prepared with plane surface cleaned with acetone, sandblasted and chemical etched and a combination of sandblasting and surface cavities.

The plates prepared with different methods show different surface morphologies. These morphologies can be seen using SEM images as shown in **Figure 2a–c**. From SEM images it was evident that the roughness of chemically etched surface is lesser than the roughness of the sandblasted surface. There are some locations on the sandblasted surface where the sand particulates diffused onto the surface of the specimens.

2.3 Single-strap SS-CFRP adhesive joint preparation

A flat marble was considered as a mould. The boundaries of the moulds were marked, and the sealant tape was attached. The pre-bond surface prepared samples were cleaned with acetone to remove chemical residues, dust and contaminations from the surface. The gap between the plates should be less than 1 mm in order to avoid the edge effect. Alternate layers of adhesive and carbon fibre were applied onto the surface of the plates (3 layers of CFRP and 4 layers of adhesive). Different accessory layers were placed over the carbon fibre layers to assist the vacuum bagging process. The accessory layers include a peel ply which is used to provide easy removal of other layers from the surface of the composite and a breather fabric to absorb excess resin during compression (vacuum pressure). Vacuum bag was applied with the help of the sealant tape, which forms a one-sided flexible mould. The mould was connected to the vacuum reservoir through vacuum hose pipe as shown in **Figure 3a** and **b**. The vacuum bag should be checked for vacuum drop (leakage). To do so the hose pipe should be closed, while the vacuum bag should be connected the vacuum gauge. A good vacuum bag should not drop more than 500 Pa in 5 min, and it is not recommended to be used if the vacuum loss is greater than 5000 Pa in 5 min. The mould should be isolated from the vacuum reservoir through proper clamping devices and allow the samples to cure for 24 hrs in the atmospheric condition. When demoulding, care must be taken as the excess adhesive would spread and stick over the entire mould cavity. Machining was done to remove the excess adhesive. The schematic of sample dimensions can be seen in **Figure 3c**.

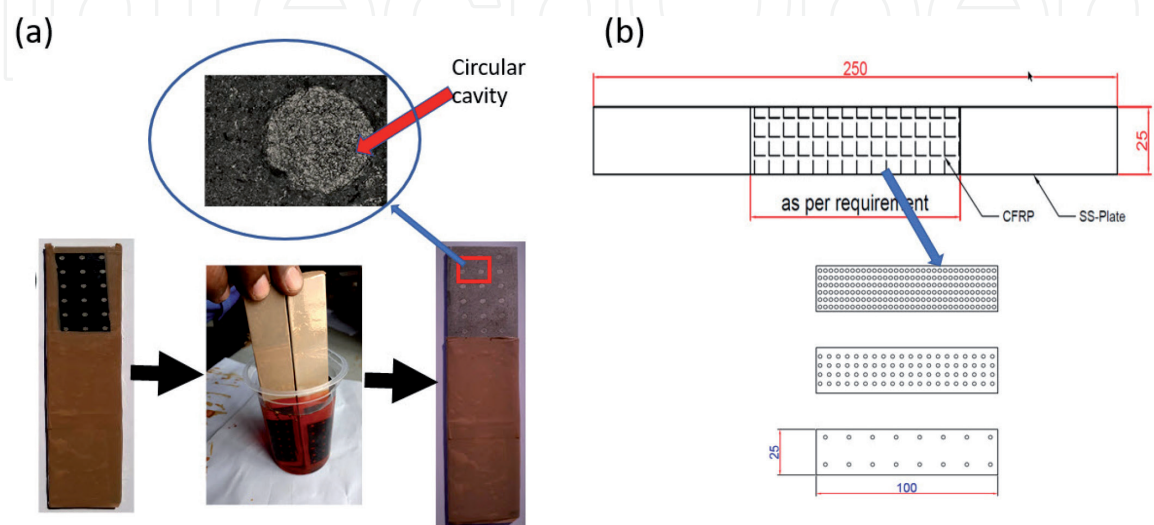


Figure 1.
(a) Chemical etching process and (b) cavities with different densities.

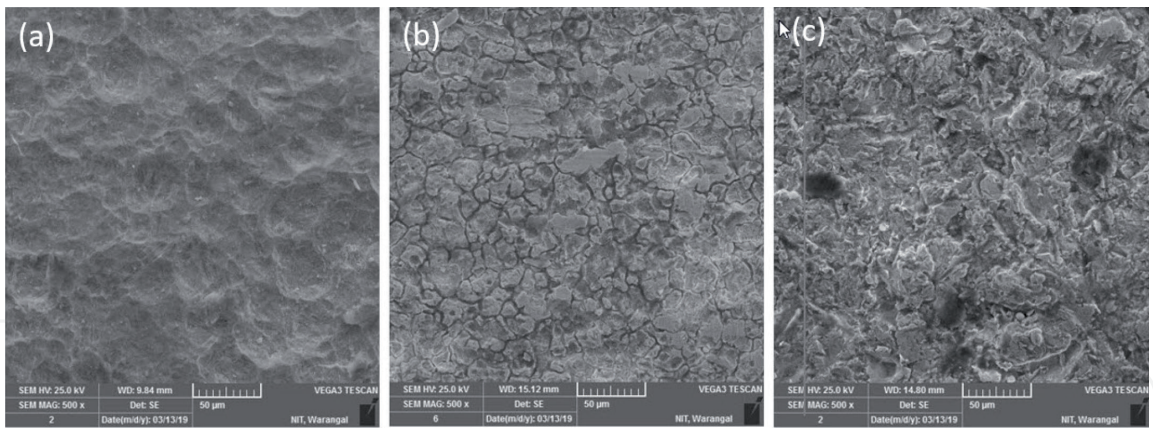


Figure 2.
SEM images (a) chemical etched surface; (b) plane surface; (c) sandblasted surface.

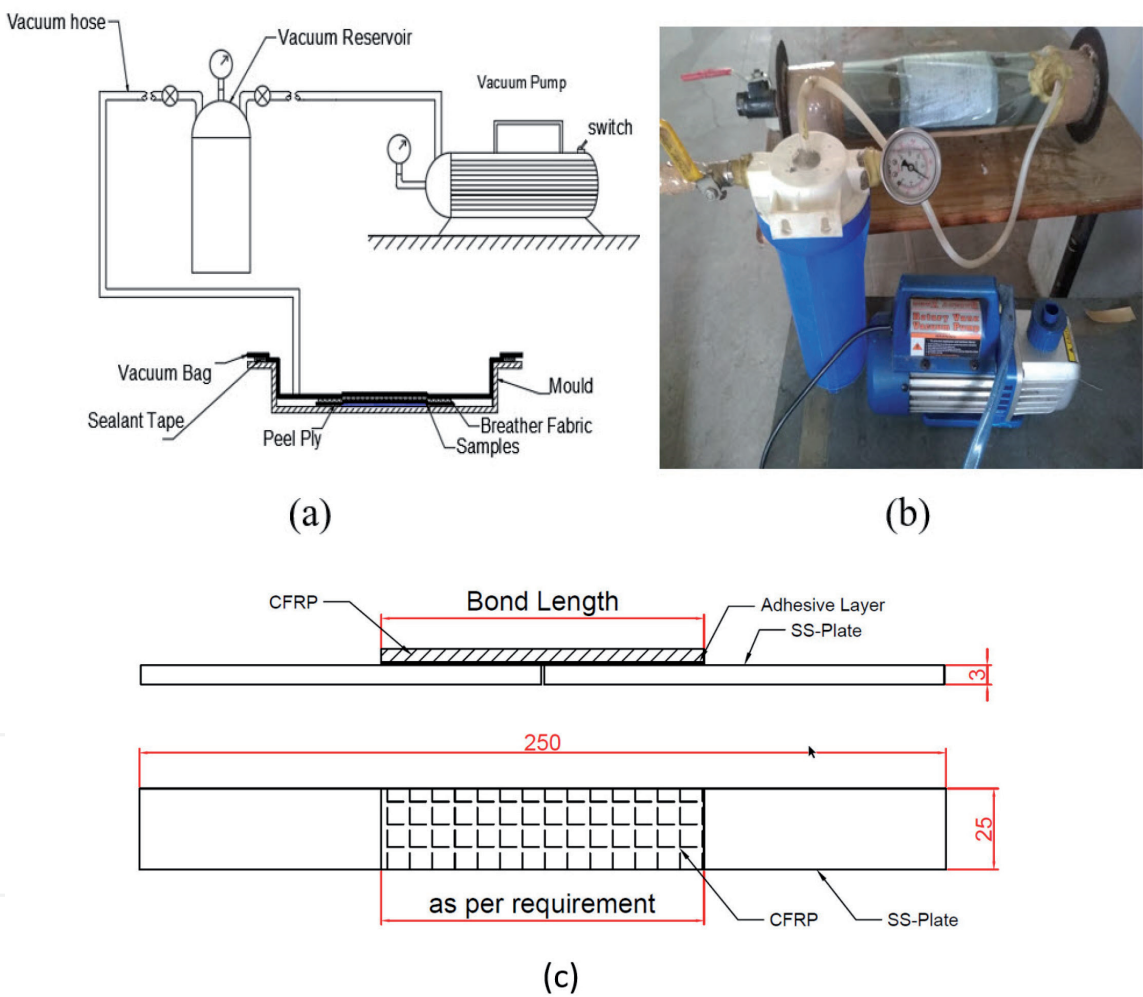


Figure 3.
(a) Schematic of vacuum infusion set-up; (b) homemade vacuum bagging set-up; (c) sample dimensions (mm).

2.4 Characterisation

The adhesive bond strength of SS plates was evaluated with tensile shear load capacity. It was measured using M/s. Jin Ahn Testing, China, with 100 kN load cell under a crosshead rate of 0.5 mm/min. The results shown here are the average values of three samples. The roughness of different pre-bond prepared surfaces was measured using 3D optical microscope (Huvitz Automatic 3D Measuring

Microscope). The surface morphology of the prepared samples was analysed using SEM micrographs taken with the help of “TESCAN VEGA3 LMU SEM”. All tests were performed at room temperature except viscosity measurement.

3. Results and discussion

3.1 Adhesive viscosity

The two-component structural adhesive (Araldite AW105 and Hardener HV 953U) used in this study has high viscosity. It is not desirable for CFRP composite making and penetration of adhesive through open pores of the surface of the adherents. The adhesive viscosity was reduced in two ways: (1) addition of low viscous nonstructural adhesive and (2) heating the adhesive to get required viscosity.

3.1.1 Addition of low viscous nonstructural adhesive

The adhesive mixture was taken with different proportions by adding nonstructural adhesive in structural adhesive. The samples were prepared as per ASTM D638 standards as shown in **Figure 5c**, and tensile test was performed. The change in the viscosity of the mixture with NSA addition was calculated using Gambill method, and it was shown in **Figure 4a**.

Single-strap SS-CFRP adhesive bonded samples were prepared by adding a low viscous nonstructural adhesive (NSA) from 0 to 100% in structural adhesive (SA). The variable parameters like surface preparation, bond length and vacuum pressure were taken at random as sand blasted, 100 and 350 mm of Hg. The samples were cured in atmospheric conditions and de-moulded after 24 h of curing. The samples were machined to remove the excess material. The samples were tested in the UTM for tensile shear load capacity of the adhesive bonded joints prepared. The results were plotted between % NSA and tensile shear load capacity as shown in **Figure 4b**. The addition of NSA decreases the load capacity of the joint and the viscosity of the adhesive mixture [17]. Generally, NSA does not take any loads they meant for holding the fibres or components together, while the SA is capable of bearing loads. Hence the addition of NSA reduces the adhesion strength.

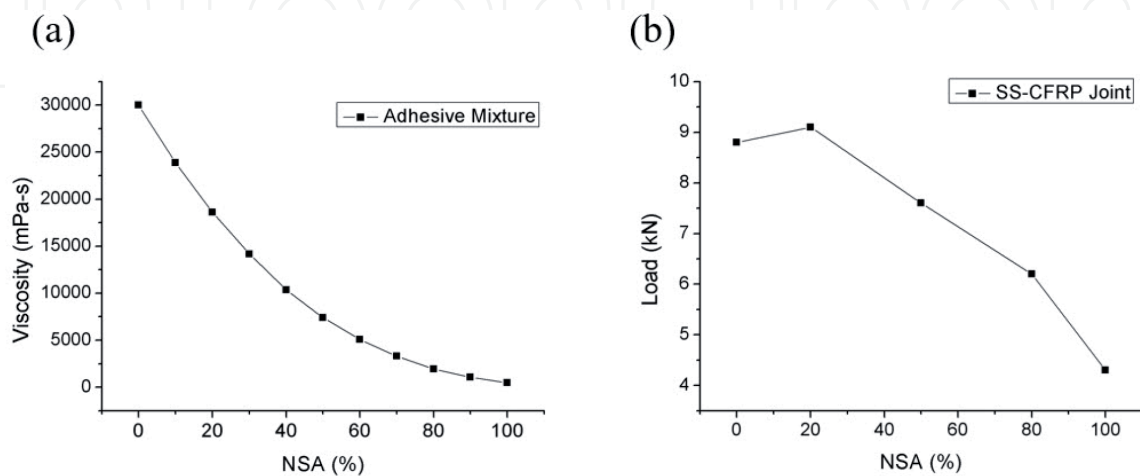


Figure 4. Effect of NSA addition on (a) viscosity of the adhesive mixture; (b) load capacity of the SS-CCRFP joint.

The adhesive joint with pure nonstructural adhesive has a load capacity of 4.3 kN. It reaches to a maximum of 9.1 kN with 20% NSA addition and 8.8 kN with pure structural adhesive. The viscosity with 20% NSA addition would be enough to penetrate through the open pores. Hence the mechanical interlocking and load capacity of the joint increases.

3.1.2 Heating effect

Curing of the adhesive makes the resin to form a cross-linked network of polymers. The structure and its mechanical properties can be changed by the way the chain network forms, which depends on the curing process. During solidification of adhesive, there is a shrinkage which creates some internal stresses in the adhesive and leads to failure of the joint well below its designed load [17]. An attempt has been made to find the effect of adhesive pre-cure temperature on tensile strength. The viscosity of adhesive was reduced by increasing the temperature of the adhesive. The adhesive was heated to 45, 55, 65, 72 and 80°C in a furnace. The viscosity at each temperature was measured using “Brookfield Viscometer”. The results were plotted between temperature and viscosity as shown in **Figure 5a**. The increased curing temperature may also change the curing rate, which in turn affects the bond strength. A series of experiments were performed on adhesive samples cured at different temperatures (45, 55, 65, 72 and 80°C) to evaluate the curing temperature effect on tensile strength of the adhesive. The sample dimensions were considered as per ASTM D638 standards. The results obtained from the tensile test can be seen in **Figure 5b**.

From **Figure 5b** and **d**, it was observed that the tensile strength of the adhesive and tensile shear load capacity of the SS-CFRP joint were increased with the increase in precuring temperature [18]. The adhesive cured at lower temperatures (45°C) has shown a brittle nature than the adhesive cured at higher temperature (80°C) during tensile test.

From **Figure 5a** and **b**, it is evident that the adhesive has shown a viscosity of 560 mPa-s at 80°C and a tensile strength of 21.1 MPa which is optimal when considering both viscosity and tensile strength as a function of temperature. In case of adhesive, joint preheat temperature limits the use of adhesive preheat temperature to 55°C. Further heating reduces the gel time, and curing it might not be good for vacuum bagging process. The supplier's data states that the increased temperature reduces the minimum curing time (“At 20°C the minimum curing time is 15 hrs, whereas at 100°C it is 10 min”). Hence the adhesive curing temperature was considered as 55°C where the minimum curing time is about 2 hrs (gel time is directly proportional to curing time) which is enough to prepare the sample.

The addition of NSA in the adhesive mixture reduces the adhesive bond strength. Heating the adhesive mixture reduces the gel time. Hence the adhesive was considered as 20% NSA + 80% SA mixture heated to 55°C which has a viscosity of 950 mPa-s.

3.2 Effect of bond length

The stress generated at the edge is maximum in the joint. As the bond length increases, the stress generated at the edge reduces. But it is up to a certain length beyond which the addition of bond length has no significance. Then the increased load that may act at the edge undergoes an elastic-plastic transition [19].

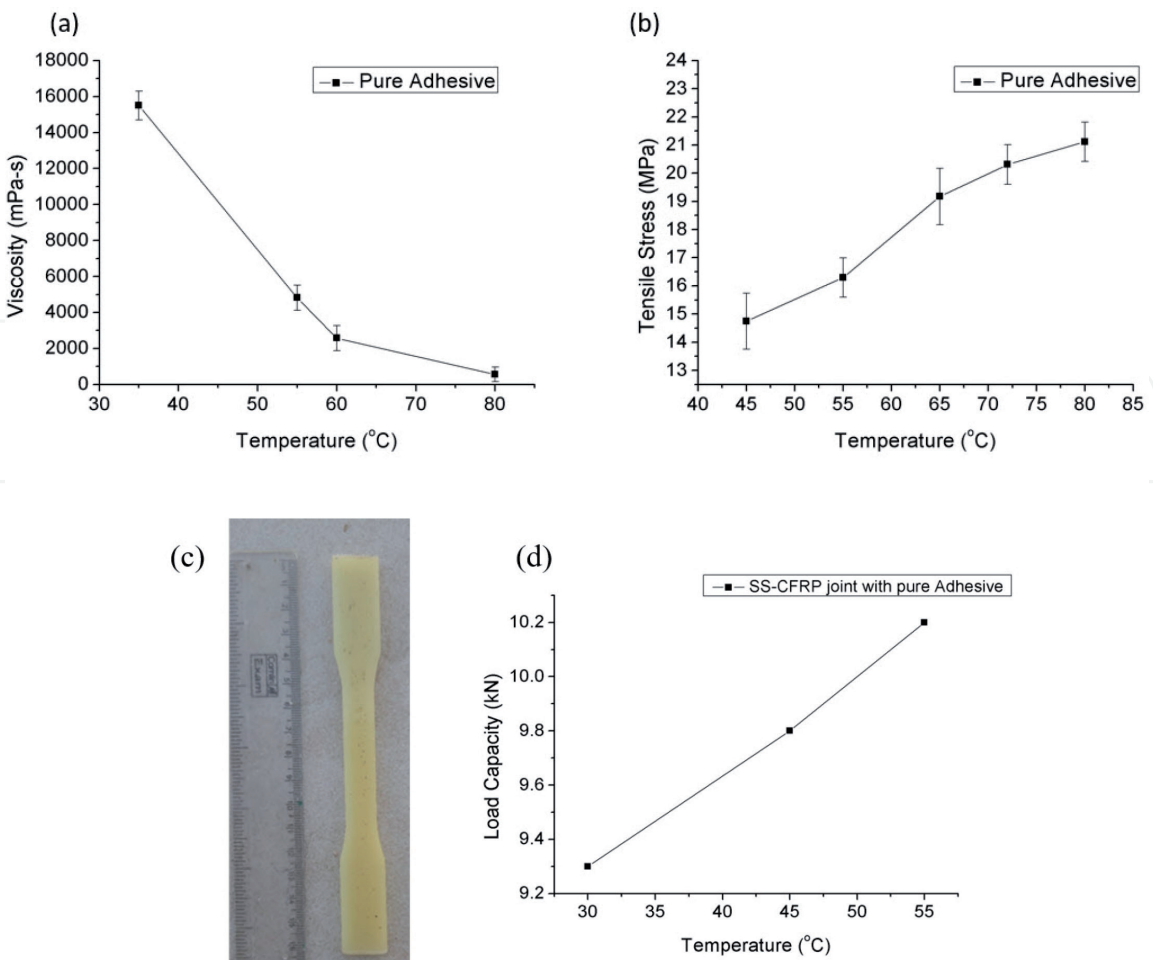


Figure 5.
(a) Viscosity of adhesive as a function of temperatures; (b) tensile strength of the adhesive as a function of temperatures; (c) adhesive tensile test sample; (d) SS-CFRP joint with different preheat temperatures.

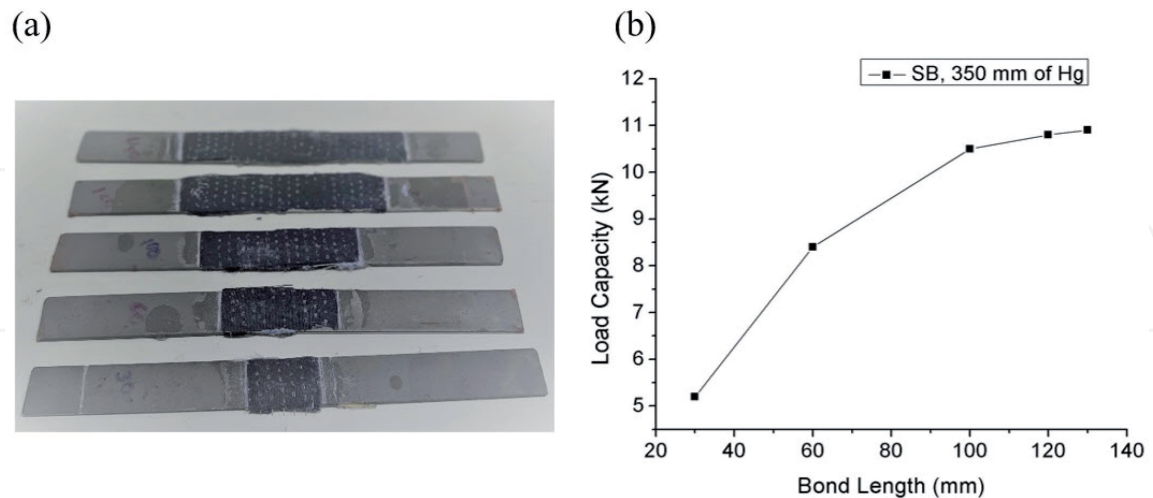


Figure 6.
(a) Samples with different bond lengths; (b) effect of bond length on load capacity.

To evaluate the effect of bond length on joint load capacity, the adhesive bonded samples were prepared with different bond lengths as shown in **Figure 6a**. The parameters considered for this study are 20% NSA + 80% SA mixture heated to 55°C, sandblasted surface and 350 mm of Hg vacuum pressure. The samples were tested for tensile load capacity, and the obtained results were plotted as shown in **Figure 6b**.

From **Figure 6b**, it has been observed that the bond load capacity of the adhesive joint increases from 5.2 to 10.5 kN, as bond length increases from 30 to 100 mm; hence the increased 70 mm bond length carries 5.3 kN load capacity. During this stage the addition of bond length will carry load linearly and reduces the stress concentration at the edge. From 100 mm to 130 mm, it has been observed that the 40 mm bond length contributes to increase 0.4 kN load capacity. During this stage, the load induces the stresses at the edges, which are greater than the elastic limit of the adhesive, so elastic plastic transition takes place, and further addition of bond length is not going to have any significance. 100 mm bond length has been considered as the adequate bond length for this experimental condition.

3.3 Vacuum pressure effect on bond strength

Compaction pressure was applied on the wet fabric with the help of the vacuum bag which is under vacuum pressure. An attempt has been made to find the effect of vacuum pressure on the adhesive bond strength of the single-strap SS-CFRP joint. Like in hand/wet lay-up, the fibres were impregnated. Initially the mould is under atmospheric pressure. Different vacuum pressures were introduced in the mould cavity. As the vacuum pressure increases, the compaction pressure acting on wet fibres increases. Hence more amount of adhesive comes out of the patch and is absorbed by the breather fabric. The air voids present in between the layers would also come out along with the excess adhesive. During this study, the other parameters considered are 20% NSA + 80% SA mixture heated to 55°C, 100 mm bond length and sandblasted surface. The prepared samples were tested on UTM for its tensile shear strength.

From **Figure 7**, it was evident that the increased vacuum pressure increases the load capacity of the prepared joint. With 100 mm of Hg vacuum pressure, the obtained joint thickness and load capacity were 4.84 mm and 9.4 kN. With 700 mm of Hg vacuum pressure, the obtained joint thickness and the load capacity were 4.32 mm and 12.6 kN. With more compaction, more amount of adhesive can be

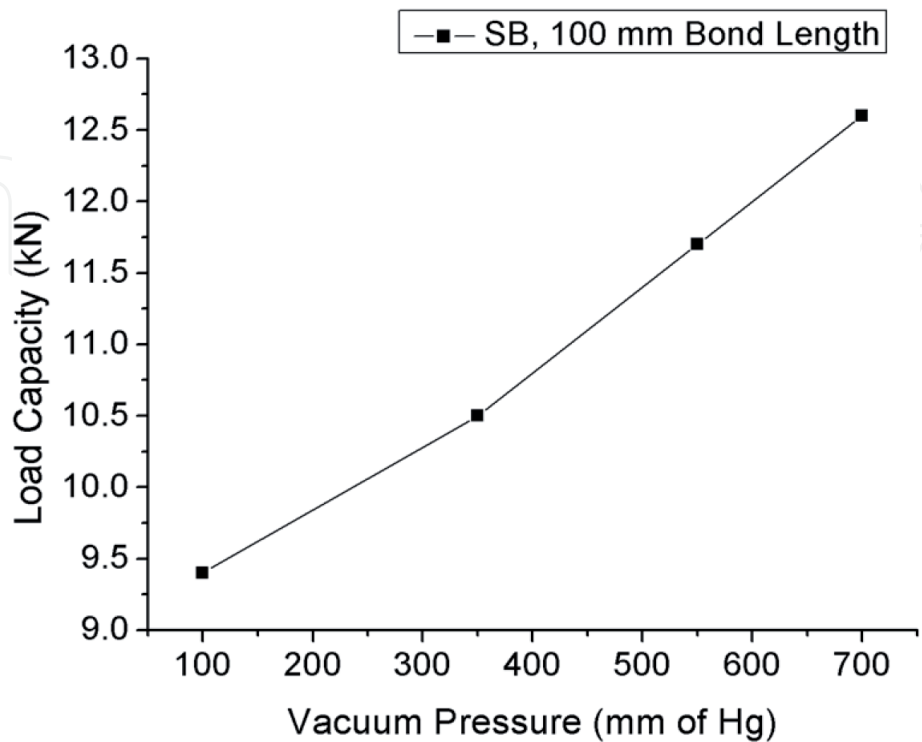


Figure 7.
Load capacity for various vacuum pressures.

squeezed out of the patch which increases the fibre volume fraction and reduces adhesive layer between SS plate and carbon fibre. Hence the adhesive bond strength increases [20].

3.4 Effect of surface texture

Surface preparation is very essential in adhesive bonding; a proper surface may provide a high bond strength. In order to find the proper surface to the adhesive bonding, the adherent surfaces were prepared with plane surface cleaned with acetone, chemical etched surface, sandblasted surface and surface texture created in the form of circular cavities at different densities with a depth of $80 \pm 5 \mu\text{m}$ as shown in **Figure 1b**. The surface roughness was measured using a 3D microscope, and the values can be seen in **Table 2**. The surface morphology of the samples was studied using SEM images as shown in **Figure 2**.

The samples for tensile test was prepared with the optimal conditions like 100 mm bond length, 700 mm of Hg and 20% NSA + 80% SA mixture heated to 55°C. Tested results can be seen in **Table 2**. The specimens were failed by delamination between steel and carbon fibre interface (no residues of fibres). The failed surfaces can be seen in **Figure 8**.

From the results, it was evident that the circular surface cavities spread over the 33% of the bonded area were shown a maximum bond strength of 14.15 kN, which is 26% higher than plane surface, 38% higher than etched surface and 12% higher than sandblasted surface. Surface texturing increases the surface roughness of the adherent which in turn increases the mechanical interlocking, and hence the adhesive bond strength increases [11].

S. no	Surface morphology	Area fraction (%)	Ra (μm)	Load capacity (kN)
1	Circular cavities	10	8.81	13.35
		25	20.73	13.83
		33	27.08	14.15
2	Sand blasted	100	0.87	12.62
3	Plane sample	100	0.68	11.24
4	Etched surface	100	0.32	10.25

Table 2.
Load capacity of different pre-bond surfaces.

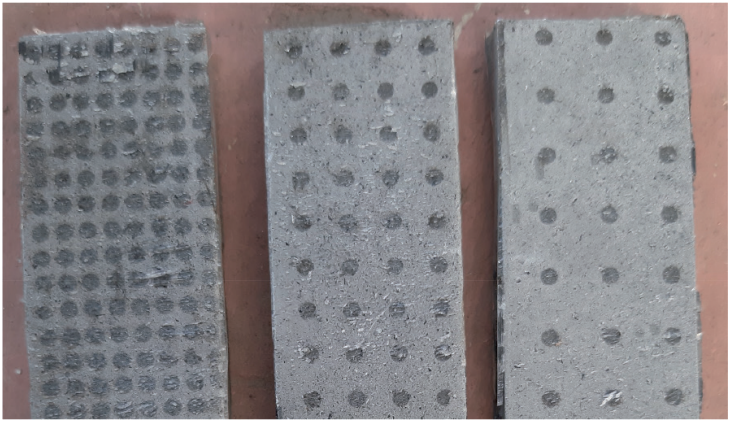


Figure 8.
Surface of the adherent after failure in tension test.

4. Rehabilitation of pipe

The damaged SS pipes were considered for rehabilitation. The rehabilitation capacity was evaluated using hydrostatic pressure test. Here, a man-made through-all defect with 10 mm diameter was machined over an 200 mm diameter pipe. This through-all hole defect was covered with a two-component solid state adhesive (M-Seal). The pipe was tested for hydrostatic pressure with M-Seal adhesive after 24 hrs. A pressure of 500 ± 30 kPa was observed with M-Seal adhesive.

The pipe surface around the defect was prepared as plane surface cleaned with acetone, etched surface, sandblasted surface and sandblasted surface with circular cavities spread over 33% bonded area. The rehabilitation was done on defect filled with M-Seal adhesive; then the composite patch proposed during the present study as 100 × 100 mm bond area (the fibres in the adhesive bonding of SS plates are aligned in the loading direction with a length of 100 mm) with [0/90]₃ carbon fibre layers, 700 mm of Hg and 20% NSA + 80% SA mixture heated to 55°C was applied.

These hydrostatic tests were conducted on the rehabilitated pipes as shown in **Figure 9**, and the results were given in **Table 3**. From the results, it is evident that the failure pressure of a pipe can be changed with surface texture. A maximum of 3852 ± 50 kPa was achieved with a pipe surface prepared with the combination of sandblasting and circular cavities. It is 62.8% higher than the plane surface.

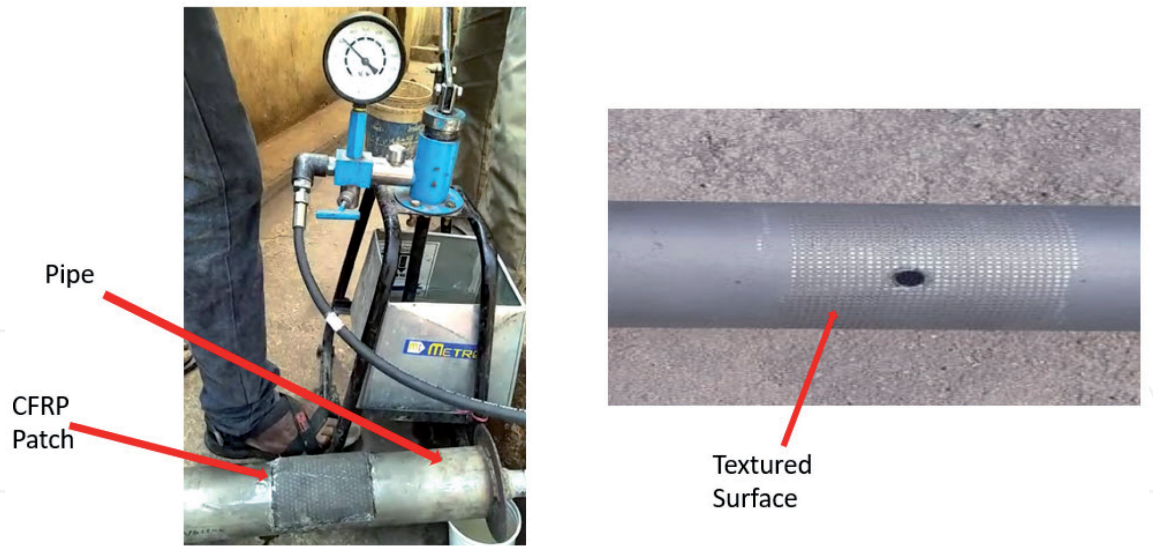


Figure 9.
Pipe hydrostatic pressure testing (left side) and surface prepared before patching (right side).

S. no	Pipe bonded area condition	Failure pressure (kPa)
1	Etched	1525 ± 50
2	Plane	2365 ± 50
3	Sandblasted	3150 ± 50
4	Surface cavities	3852 ± 50

Table 3.
Hydrostatic pressure of pipes.

5. Conclusions

In the present work, the rehabilitation of damaged pipe was done using CFRP patch made with vacuum bagging process. The optimal parameters for rehabilitating the damaged pipe was derived from the experimental results of “the adhesive bonding of SS plates using CFRP patch made with vacuum bagging process”. The parameters considered are vacuum pressure, CFRP/adhesive combination and pre-curing temperature, bond length and surface texture. Tensile test was considered to evaluate the bond strength of SS plates, and hydrostatic pressure test was considered to evaluate the bond strength of rehabilitated SS pipes. The experimental data was analysed, and the following conclusions were drawn.

- The viscosity of the adhesive used for the present study was high, and it was reduced with the following methods:
 - The viscosity was changed by adding the low viscous nonstructural adhesive. This addition was reducing the bond strength. Hence it was taken as 20% NSA.
 - Heating of adhesive was shown a significant change in the viscosity and its strength. The strength of the pure adhesive and SS-CFRP joint was increased with increase in curing temperature. But it reduces the gel time. At 55°C the minimum curing time is about 2 hrs which is enough time for the present study.
 - 20% NSA + 80% SA mixture heated to 55°C was considered as adhesive conditions for further study.
- The bond length from 30 to 100 mm might increase the load capacity by approximately 101% (from 5.2 to 10.5 kN). With an increase in bond length from 100 to 130 mm, the load capacity increased by 3.8% (10.5–10.9 kN). Hence, 100 ± 5 could be considered as optimal bond length.
- Vacuum pressure has shown a significant effect on the thickness of samples prepared and the strength of adhesive bonding.
 - At low vacuum pressures, the compaction pressure on the wetted carbon fibre preform is low. Hence a thick layer of adhesive forms between carbon fibre and SS plates which reduces the bond strength.
 - With 100 mm of Hg vacuum pressure, the obtained joint thickness and load capacity were 4.84 mm and 9.4 kN. With 700 mm of Hg vacuum pressure, the obtained joint thickness and the load capacity were 4.32 mm and 12.6 kN.
- The pre-bond surface preparation is a must to have a good adhesive bonding between two adherents. The present study included the surface preparations as sandblasted, chemical etched, plane surface cleaned with acetone and surface texture with circular cavities at different densities.
 - A maximum of 14.15 kN load capacity was observed with the combination of sandblasted surface with circular cavities occupied at 33% of bonded area, whereas the surface with only sandblasting has shown a load capacity of 12.62 kN which is 12% less.
 - The surface roughness of different prepared samples was also studied, and it was evident that the adhesive bond strength is increased with increase in

surface roughness. This is because of the increased mechanical interlocking with roughness of the surface.

- The damaged pipe was prepared with different surface textures and rehabilitated with the optimal parameters obtained with the tensile data of the SS plates. A maximum of 3852 ± 50 was achieved with a pipe surface prepared with the combination of sandblasting and circular cavities. It is 6.7 times higher than M-Seal covered cavity and 62.8% higher than the plane surface.

Vacuum bagging process has many advantages in fabricating composite laminates. The proper use of vacuum bagging process in rehabilitation process may result in strong and eco-friendly adhesive bonded joint.

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Conflict of interest

The authors have no conflict of interest.

Author details

Syam Kumar Chokka, Beera Satish Ben* and Kowtha Venkata Sai Srinadh
National Institute of Technology, Warangal, India

*Address all correspondence to: drsathishben@gmail.com

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References

- [1] Lu Y, Li W, Li S, Li X, Zhu T. Study of the tensile properties of CFRP strengthened steel plates. *Polymers*. 2015;**7**(12):2595-2610
- [2] Osouli-Bostanabad K, Tutunchi A, Eskandarzade M. The influence of pre-bond surface treatment over the reliability of steel epoxy/glass composites bonded joints. *International Journal of Adhesion and Adhesives*. 2017;**75**:145-154
- [3] Hollaway LC. The evolution of and the way forward for advanced polymer composites in the civil infrastructure. *Construction and Building Materials*. 2003;**17**(6-7):365-378
- [4] Hollaway LC. A review of the present and future utilization of FRP composites in the civil infrastructure with reference to their important in-service properties. *Construction and Building Materials*. 2010;**24**(12):2419-2445
- [5] White DM, Daniell WE, Maxwell JK, Townes BD. Psychosis following styrene exposure: A case report of neuropsychological sequelae. *Journal of Clinical and Experimental Neuropsychology*. 1990;**12**(5):798-806
- [6] Castillo L, Baldwin M, Sassine MP, Mergler D. Cumulative exposure to styrene and visual functions. *American Journal of Industrial Medicine*. 2001;**39**(4):351-360
- [7] Jeong H. Effect of void on the mechanical strength and ultrasonic attenuation of laminated composites. *Journal of Composite Materials*. 1997;**31**(3):276-292
- [8] Bowles KJ, Frimpong S. Void effects on the interlaminar shear strength of unidirectional graphite-fiber-reinforced composites. *Journal of Composite Materials*. 1992;**26**(10):1487-1509
- [9] Robson JE, Matthews FL, Kinloch AJ. The strength of composite repair patches: A laminate analysis approach. *Journal of Reinforced Plastics and Composites*. 1992;**11**(7):729-742
- [10] Strong AB. *Fundamentals of Composites Manufacturing: Materials, Methods, and Applications*. 2nd ed. Dearborn: Society of Manufacturing Engineers; 2008
- [11] Guo L, Tian J, Wu J, Li B, Zhu Y, Xu C, et al. Effect of surface texturing on the bonding strength of titanium–porcelain. *Materials Letters*. 2014;**131**:321-323
- [12] Hadigheh SA, Kashi S. Effectiveness of vacuum consolidation in bonding fibre reinforced polymer (FRP) composites onto concrete surfaces. *Construction and Building Materials*. 2018;**187**:854-864
- [13] Esnaola A, Tena I, Saenz-Dominguez I, Aurrekoetxea J, Gallego I, Ulacia I. Effect of the manufacturing process on the energy absorption capability of GFRP crush structures. *Composite Structures*. 2018;**187**:316-324
- [14] Zhang D, Heider D, Gillespie JW Jr. Void reduction of high-performance thermoplastic composites via oven vacuum bag processing. *Journal of Composite Materials*. 2017;**51**(30):4219-4230
- [15] Teng JG, Yu T, Fernando D. Strengthening of steel structures with fiber-reinforced polymer composites. *Journal of Constructional Steel Research*. 2012;**78**:131-143
- [16] Hart-Smith LJ. *Advances in the analysis and design of adhesive-bonded joints in composite aerospace structures*. 1974

[17] Schneider LFJ, Cavalcante LM, Silikas N. Shrinkage stresses generated during resin-composite applications: A review. *Journal of Dental Biomechanics*. 2010;**2010**:131630

[18] Singh JIP, Singh S, Dhawan V. Effect of curing temperature on mechanical properties of natural fiber reinforced polymer composites. *Journal of Natural Fibers*. 2018;**15**(5):687-696

[19] Schnerch D, Dawood M, Rizkalla S, Sumner E, Stanford K. Bond behavior of CFRP strengthened steel structures. *Advances in Structural Engineering*. 2006;**9**(6):805-817

[20] Amirkhosravi M, Pishvar M, Altan MC. Improving laminate quality in wet lay-up/vacuum bag processes by magnet assisted composite manufacturing (MACM). *Composites Part A: Applied Science and Manufacturing*. 2017;**98**:227-237