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Article

Testing epoxy strength: The high strength claims of Selleys's Araldite Epoxy Glues

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SUMMARY

Epoxy resin is a type of thermosetting polymer that is considered among the best matrix materials with excellent properties including high flexibility, good dielectrics, chemical inertness, and water repellency. The strength of epoxy can be influenced by cross-linked density and the incorporation of a variety of solid particles of butadiene. It is important to understand the techniques used to improve the adhesion strength of the epoxy resin, especially for consumer applications such as repairing car parts, bonding aluminum sheeting, and repairing furniture or applications within the aviation or civil industry. Selleys is a well-known Australian company specializing in cleaning products, adhesives and sealants; their Araldite epoxy makes specific strength claims emphasizing that the load or weight that can be supported by the adhesive is 72 kg/cm^2. Our experiment aimed to test the strength claims of Selley's Araldite Epoxy by gluing two steel adhesion surfaces: a steel tube and bracket. Altogether, a 55 mm surface was used, meaning the load held by the brackets would be 41.25 kg. Loads were added to the bracket as a destructive tensile load test were conducted. To avoid batch effect, three tubes of Selleys's Araldite epoxy were used. Our results showed that there was a significant difference between actual load and the expected load (41.25 kg) (a two-tailed *t*-test with *p*-value < 0.05 with a fracture stress ranging from 0.019 MPa-0.095 MPa, disputing the claim that Selleys's Araldite epoxy can hold up to 72 kg/cm^2 as we expected the p-value to be > 0.05 in order to accept the claim. The experiment showed that there is a lack of consideration by Selleys for adhesion loss mechanisms and environmental factors when accounting for consumer use of the product leading to disputable claims.

INTRODUCTION

Thermosetting plastics are a type of polymer formed by a network of covalent bonds; usually cross-linked with pressure or heat (1). Thermoset bonds are irreversible cross-links, created by covalent bonds, which are chemical bonds in which electrons are shared between atoms, producing a polymer chain (2). Epoxy resins are common thermoset plastic polymer matrix composites, which are considered the best amongst matrix materials (3). Epoxy resins are widely used for many adhesive applications because of its excellent properties in high flexibility, good dielectric chemical inertness and water repellency (3). There have been significant production studies on new epoxy resins (4-7) with many companies aiming to develop a strong and durable polymer for adhesion. However, often the toughening of epoxy resins via high density cross-linking causes the material to become brittle, consequentially causing poor resistance to crack propagation (4).

Epoxy resins are usually presented as two parts that are combined in equal proportions, the liquid resin and the catalyst, also described as the curing agent which allows surface hardening. Amines, anhydrides or Lewis acids are used as a curing agent to accelerate curing whilst also improving thermal stability of cured resins (8).The properties of epoxy resin can be directly affected by both the curing agent and the curing process, due to the cross-linking between epoxy molecules and reactive groups (9). Lower cross-link density improves toughness and reduces the shrink rate during curing, whilst higher cross-link density improves chemical resistance but lowers the strain, which is the deformation of a material before fracturing (9). Approaches used to improve the toughness and strength of epoxy resins include the incorporation of butadiene and of solid particles, such as acrylonitrile copolymers terminated with reactive groups (carboxyl, amine, hydroxyl or epoxy) (4). Through cross-linking polyurethane with epoxy resins, researchers were able to conclude a significant improvement of tensile strength, but again a reduction in properties such as compressive yield strength or elastic modulus (10-11).

It is important to understand and optimize techniques used to improve the adhesion of epoxy resins, especially for consumer applications. The crosslinking between liquid epoxy resins with solid particles and/or butadiene will directly have an impact on the properties of the epoxy, most notably its strength. Mechanical interlocking of a surface also plays a vital role in strength, as cavities and pores within a surface allow a larger surface area for electrochemical reactions, inevitably increasing adhesive strength. (12). Mechanical interlocking is the joining of two dissimilar materials as the adhesive material penetrates pores and irregularities (13). Concurrently, research into various adhesions materials or

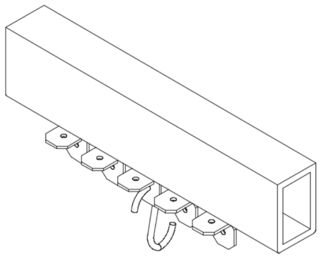

Figure 1. Fusion360 CAD drawing of experimental setup. The actual experiment had 20 brackets along the steel tubing.

"coatings" within the aviation, civil, and renewable energy (more specifically wind turbines) industries have strongly examined various adhesion and environmental properties of epoxies as a protective surface coating (14-15). Lima and Guilemany noted that the quality and performance of coatings are dependent on the cohesion between the coating and the substrate, or surface (14). Their work also mentioned the possible influences on the quality and abilities of the adhesion such as oxidation, splat morphology and residual stresses (14). Other adhesion materials, such as fly ash, chemical vapor disposition and plasma sprays that have been utilized similarly to epoxy resin, have also been shown to be influenced by various environmental influences such as oxidation and temperature, with strengths varying from 6-27 MPa (depending on the material tested) (6, 16). Scientists are examining the optimal properties, as well as the strengths and weaknesses, of adhesion materials to ensure protection of the parent materials, safety for users, and reduction of waste. There are various external influences within actual applications, commercial companies may only test epoxy/adhesion products within ideal conditions in which the materials are not inherently exposed to possible inconsistencies that's users may face. This discrepancy creates differing effects within consumer's use compared to specific company claims.

Some manufacturers such as Selleys make specific claims in the strength of their epoxies. For example, Selleys's 75 kg, 5-minute Araldite epoxy claims that it can hold 75 kg/cm^2 when applied to a variety of materials. To confirm the specific strength claim of Selleys's Araldite epoxy glues, our study aimed to investigate the specific strength through load testing. Our load testing consisted of Specifically, we hypothesized that the epoxy resin must be able to hold the weight as indicated on the packaging (75 kg/cm^2 on steel). Therefore, there should be no significant difference between the data obtained from the test and the claims in order to accept this claim. However, this was not the outcome of the experiment with a p-value < 0.05 suggesting the adhesive cannot hold up to 75 kg/cm^2 as suggesting in its packaging and commercial.

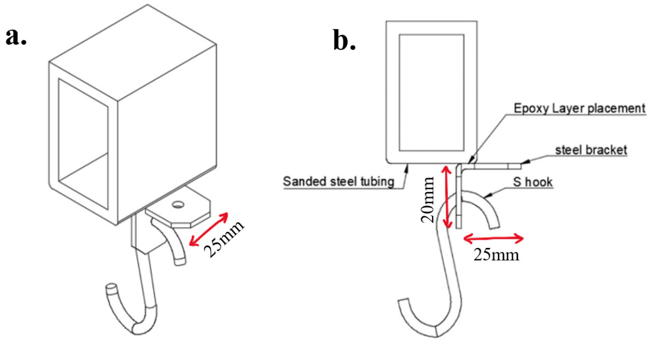

Figure 2. Fusion360 CAD drawing. a) Side view of a section of the experimental set up and labeled equipment. **b)** Perspective view. Dimensions of the steel bracket also included. We see that the epoxy layer was only placed on a section of the steel bracket 0.55 cm^2.

RESULTS

We tested the claim of Selleys's Araldite epoxy resin holding 75 kg/cm^2 was tested through a destructive tensile load test. Using Selleys's 5-minute Araldite epoxy adhesive (1000 mL liquid epoxy resin and 80mL Aliphatic Amines), 20 x 25 mm galvanized steel brackets were adhered to steel tubing strip for destructive tensile load testing (**Figure 1**). The strength of the epoxy adhesives was determined by the load held by the bracket joints (**Figures 2 and 3**). Throughout testing, the load held by the epoxy resin joint broadly varied having a mean of 28.83 kg and a standard deviation of 10.19 kg, with only a few tests reaching or exceeding the expected

Figure 3. Actual experimental set up of steel joints, S hook and milk crate with weights.

Statistics	*Weight at Epoxy Failure Results*
Mean (kg)	28.83
Sample Size	75
Standard Error (kg)	1.18
Median (kg)	31
Standard Deviation (kg)	10.19
Kurtosis	-0.52
Skewness	-0.02

Table 1. Descriptive statistical showing mean, standard error, median, standard deviation kurtosis and skewness.

load held (41.25 kg) (**Table 1**). A scatterplot compared both load held and the expected load, showed that there was a notable difference between the load held and the expected load, with many of the values of weight held before failure being < 41.25 kg and a few exceeding 41.25 kg (**Figure 4**). The *t*-Test: Two-Sample Assuming Unequal Variances, used to compare the load held and the expected load held found that there was an extremely significant difference between load held and the expected load; *p*-value = 2.1E-16 (**Figures 4 and 5**). Therefore, we rejected the null hypothesis that there would be no difference between our observed load and the expected load. Furthermore, the load held during testing was not equal to the expected load; overall contradicting pervious claims made by Selleys's Araldite epoxy resin.

The histogram established that the data collected of weights held by epoxy is roughly symmetrical and has a normal data distribution (**Figure 4**). The kurtosis (-0.5) and skew (-0.02) further emphasized that the data was normally distributed (close to 0). There is a higher frequency of loads being supported at around 35-40 kg, with a small peak within the 20 kg range. We also saw that the higher loads such as 40-51 kg showed decreases in frequency as only a few had reached the expected load or exceeded the expected load. Additionally, a descriptive statistical test showed that the average weight held by the joints was only 28.83 kg, despite the expected load being 41.25 kg (**Table 1**).

The weights that failed between at 10-25 kg demonstrated a lack of adhesion on both joint surface of the steel bracket and bar, with the dried epoxy residue being minimal on the steel bar. Whereas stronger joints had residue (fragmented) on both joint surfaces evident throughout testing. The appearance of the fracture points on stronger joints were jagged and rough suggesting a brittle material when the epoxy resin is cured; whereas the weaker epoxy joints exhibited smooth when joints were apart. Additionally, our fracture stress data showed that the tensile strength ranged from 0.019 MPa-0.095 MPa with an average of 0.053 MPa and an expected fracture stress of 0.077 MPa. The fracture stress results further propose that the material was very brittle within our study.

DISCUSSION

Epoxy resins and glues have many strong adhesive properties, making them desirable for many structural applications. However, epoxy's strength can often be exaggerated by manufacturers. The Australian company and manufacturer Selleys's made specific strength claims for their commercially available Araldite epoxy glue, their tv ad states "It's strong enough to hold up to 75 kilos, so you can repair metal, wood, glass, leather and a whole lot more" (17). The claims made within the ad do not coincide with the packaging in which it states that it can hold up to 75 kg/cm^2 on steel (18). The advertisement clearly shows that a large surface area has been used therefore the strength claim are not being truly represented to the consumer. We hypothesized that Selleys's epoxy will affirm its claim; although our destructive tensile load testing showed a significant difference between load which was an average of 28.83 kg and the expected load of 41.25 kg, with a *p*-value < 0.05. Our results also established that average weight held during the test was only

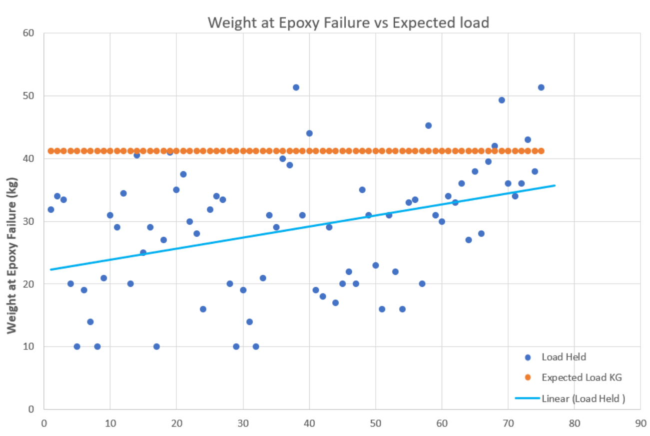

Figure 4. Scatterplot of the *n* = 75 weight at epoxy failure vs the expected load. It is notable that most values of weight at epoxy failure are below the expected load with few values exceeding the expected load.

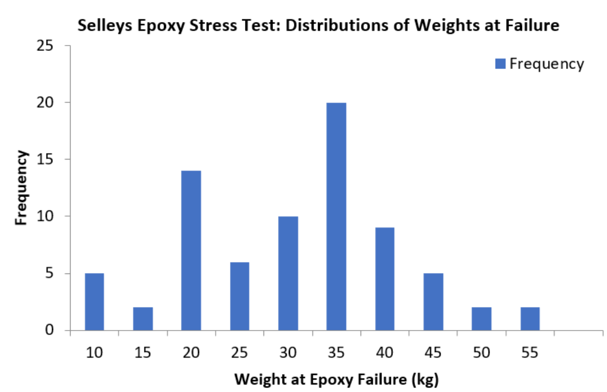

Figure 5. Histogram of weight held by Selleys's Araldite Epoxy Glue. The histogram exhibits a normal data distribution. Our overall sample size was *n* = 75. Numbers on the x-axis represent the center of the bin with a range of weights held 10kg – 55kg. The y-axis show the frequency/number of the weights held.

28.83 kg with a mode of around 20 kg. Thus, we rejected our null hypothesis that there would be no difference between our observed load and the expected load. Therefore, we gathered evidence to support that Selleys' claims may not always hold up in all circumstances.

In this study a large sample size (n = 75) as well as three preparations of epoxy resins were used to test the specific strength claims of Selleys's epoxy glue, allowing it to be heterogeneous in respect to the load held by the Selleys's Araldite 75 kg glue. We knew that surface preparation was an important parameter that will directly affect the quality of the bonded joint (5). There was also notable efforts in ensuring that surface preparation was optimal for mechanical interlocking despite this not being suggested by the packaging and website (18). We followed direct instructions by Selleys's Araldite 75 kg glue precisely ensuring that all conditions for excellent adhesion is satisfied. This included allowing for adhesion onto steel which was specifically noted on the packaging, "holds up to 75 kg per cm^2 when fully cured on steel" and providing an adequate bonding time of 24 hours. Almost all factors ensuring the product's strong bond was considered and applied within this experiment and tested with a large sample size allowed the data to be representative of product as well as allowing the us to have reproducible data.

Despite this study demonstrating the true strength and nature of the epoxy product under our experimental conditions, there are many factors that can affect the adhesion strength of the epoxy resin. We assumed that Selleys's did not account for a variety of factors such as wet adhesion loss, bar fabrication , or possible impurities with the material or loose particles within the working environment such as dust (12). Temperature and moisture present in our lab may have affected the results of the tested epoxy joints; our testing environment consisted with warm temperatures between 14-25.7°C and humidity levels of 70-72%. Researchers have shown that these adhesion loss mechanisms and environmental factors can have adverse effects on the bar adhesion of epoxy resins on steel surfaces, especially for the transportation and construction industry (12). Recent studies by Lettieri and Frigione's concluded that high humidity levels up to 80% caused the epoxy resin to increase water absorption/moisture causing physical aging, leading to an increase of the reduction of properties such as stiffness, elongation and yield strength (19). Whilst temperature can also contribute to adhesion loss as it can cause an acceleration of polymer disbandment in high temperatures or quenching in cooler temperatures resulting in a brittle material (12). It is also possible that impurities such as dust or moisture could have entered the bonding site, thus creating an inadequate surface profile reducing mechanical interlocking between the epoxy resin and the steel surface and ultimately impairing the coating's adhesion (12).

Bar fabrication was another factor that could have affected the results of this study causing a random error within the test as almost 20 bonded joints were placed on a length of bar and tested continually. As a load is exerted on one test joint it will cause a shear stress at the steel interface weakening the adhesion of the epoxy film through mechanical action. Additionally, joints that only held 10-25 kg had a large absolute error ranging between ±5 kg to ±250 g as we added the weights in increments. Shear stress is created through the load causing the steel to slightly slag and bend during the testing process; whilst with the addition of vibration created by the load failure likely created a loosening between the coating and the steel surfaces. There is some certainty that bar fabrication was a strong underlying factor considering there was a large variation in weights held as testing continued. The inconsistency in weights being held before epoxy failure suggests that the continual vibrations created by the bar fabrication has affected adhesion strength. We assumed the effect of bar fabrication, which is suggested in the free body diagram that examines how the load carried by the middle joint causes possible flexing, resulting in weakening the adhesion of the epoxy on both surfaces (**Figure 6**). Again, despite all

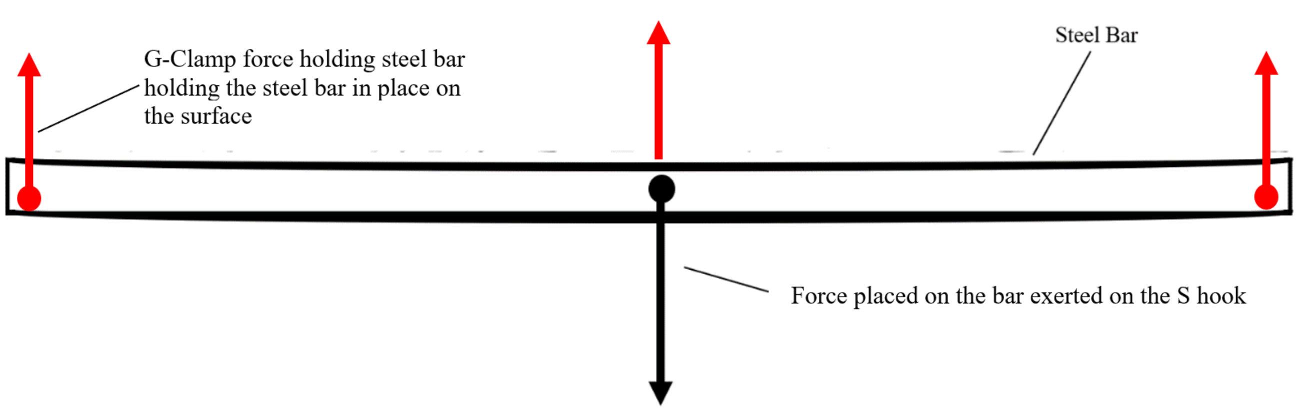

Figure 6. Freebody diagram examining the effects of a force exerted on the steel bar from the weights placed on the S hook. G clamps were placed on the two end sides of the bar, this is the force holding the bar up, the red arrow represents the force of the G clamps. The force was concentrated within a range of areas along the steel bar through the S hook and weights in the crate, this is presented by the black arrow, this diagram only represents one point.

these unforeseen limitations, we still had reproducible data through our large sample size ensuring both reliability and validity within the experiment.

For future studies, we recommend that surface joints should not be done collectively on one single steel bar. Rather, the steel bar tubing should be cut up into pieces to be paired with a single bracket, avoiding a potential bar fabrication. Whilst surfaces should be ensured for no defects such as dust and test area should be kept dry. Weights should also be added in small and similar increments to reduce absolute error making the test more accurate. We must also recognize that there are many limitations within this study, including high humidity and warm temperature creating a moist surface that likely reduced the epoxy's adhesion properties and a lack of consideration of how the time exposed stress caused by the load can cause variation to the strength of adhesion. Also, the estimation of the volume or the thickness of epoxy utilized on each joint and approximating curing time which was expected to be 24 hours to be fully cured which will also affect the strength of adhesion.

Since we only tested three tubes of product, it may be difficult to represent the product generally. Nevertheless, from this study, it is clear that specific strength claims made by Selleys's production were difficult to attain as they do not account for adhesion loss mechanism and environmental factors, that significantly affect the adhesion between joints. We had a few replications that were able to exceed expected load of 41.25 kg, however this shows the difficulty attaining proper accounts of real-world conditions when comparing to company conditions. Consumers should be cautioned, to ensure safe practices and use of the product.

Ultimately our aim for this study was to test the high strength claims of Selleys's 75 kg/cm^2 Araldite epoxy. Studies have shown the strength of epoxy can be affected by several factors including the degree of crosslinking through the incorporations and ratio of solid particles and of butadiene (4), whilst adhesion loss mechanisms such as wet adhesion loss, temperature and bar fabrication (12) can affect the strength and adhesion of the epoxy resin on the joint surfaces. Our results showed a 2.1E-16 *p*-value, which rejected our hypothesis that there should be no significant difference between the actual load and the expected load (the claim). The experiment has revealed that the claims made by Selleys's Araldite 75 kg/cm^2 epoxy may only be upheld under optimal lab conditions. The product has not considered the variety of adhesion loss mechanisms and environmental conditions that most likely affected the adhesion strength capabilities of the epoxy resins. Further studies may investigate how to improve or avoid certain factors that will cause the strength of the epoxy resin to deplete within the curing time. Through this study, we can caution consumers and users when applying this epoxy in practical load bearing applications.

MATERIALS AND METHODS

Materials and Surface Preparation

Selleys's 5-minute Araldite epoxy adhesive (1000 mL liquid epoxy resin and 80 mL aliphatic amines) was used for this experiment testing their claim of holding 75 kg/cm^2 (when cured to steel). A 25 x 25 x 20 mm^3 L-shape, galvanized steel bracket that had a thickness of 2 mm was used as a joint surface and was adhered to a section on a length of steel tubing (**Figure 2**).

In surface preparation, paint was stripped from the steel tubing of joint surfaces and then sanded with 180 grit sandpaper at a 45° angle, whilst only one face of the bracket was sanded. Both surfaces were wiped with acetone, ensuring the removal of contaminants including oils, dust, and loose layers previously sanded off. The surface roughness created by sanding allowed mechanical interlocking and surface texture for increased area bonding.

Experimental Protocol

Once materials were prepared, a small amount of epoxy resin was extruded out and mixed with a wooden rod. Using the wooden rod, only a small approximated amount of epoxy was placed onto the edge of the steel tube. Another small amount of epoxy was placed onto 20 x 4 mm section (minus 25 mm of cut corners on brackets) (**Figure 1**) of the sanded bracket face closest to the bended angle of the bracket, which allowed the joint to be close to where the load was focused. Masking tasking tape was then used to let the joint be held in place. Selleys's instructions were followed thoroughly, this involved cleaning and drying the surface of the materials used, dispersing equal parts of the epoxy and mixing both parts together thoroughly and the mixture was then applied to both surfaces of the job. The instruction stated to not apply undue strain to the bond for 30 minutes and allow the joint at least 16 hours to reach maximum strength we also did this to ensure optimal adhesion of the product. For our case, the joint was allowed to cure for 24 hours before tensile load testing, we also smeared approximately 3-4 mm worth of product on one side of the bracket. The contact area in which the epoxy resin occupied on the bracket was 0.55 cm^2. We only used a small section of the bracket to apply the epoxy resin to perform the experiment within a short duration, as less weights would be needed to reach a point of failure. Therefore, to determine the load the joint could hold, the formula below was used:

$$\text{Total Surface Area x Load per cm}^2 = \text{Load Held}$$
$$\therefore 0.55 \text{ cm}^2 \times 75 \text{ kg} = 41.25 \text{ kg}$$

After 24 hours the brackets was cured and adhered onto the steel tubing, this set up was clamped face down on the edge of a table with three 'G' clamps (one on each side and one in the middle) for even support. The steel tube must be clamped tight ensuring it will support the loads placed on the brackets. A 'S' hook was placed onto the bracket with a supporting milk crate to place weights (**Figures 3 and 5**). A

10 kg weight was added initially before increments of 2 kg (up to 6 kg), 1 kg (up to 24 kg) and 500 g weights were added in (**Figures 3 and 5**). Once the joint has failed the weights held is counted and recorded, the experiment is repeated 75 times to obtain a significant sample size. To avoid pseudo repetition, three tubes of each epoxy glues tested were used alternatingly ensuring no factory defects were present resulting in a possible systematic error.

Fracture Stress Calculation

The fracture stress of epoxy resin may depend on the crosslinking agent as well as the amount of resin used on the adhesion surface (20). Thus, to understand the material's ability to absorb energy endured by the weights we calculated the fracture stress based on the stress/strain formula shown below.

$$\text{Fracture Stress} = [\text{Area } (N/m^2)]/[\text{Force } (N)]$$
$$\therefore\ \sigma = P/A = P/[5.5E^{-5}\,m^2]$$

Statistical Analysis

As a claim is being tested on our hypothesis through comparing the load held during testing and the expected weight of 41.25 kg, a *t*-test, two-sample assuming unequal variances was used to determine the statistical significance between the load held and the expected weight. The results of the load held were tested for normality through a descriptive statistical test mainly determining the kurtosis and skewness; whilst the standard deviation of the expected load was also obtained through a descriptive statistical test (**Table 1**). Finally, to visually represent the distribution of the loads held by the epoxy, a bin range was entered (10-55) to create a histogram for the loads held.

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