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Evaluating the Adhesive Properties of Four Types of Conventional Adhesives

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HIGHLIGHTS

- The butt and single lap joint are the powerful techniques to evaluate the adhesives.
- Quasi-static loads have been used effectively to find the response of adhesives.
- MS Hybrid Polymers can employ in applications that have strength with flexibility.
- MS Hybrid Polymers has the cohesive failure in both the normal and shear forces.

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ABSTRACT

The development of manufacturing technology led to the appearance of various products that need effective types of adhesives with good strength and durability in different types of joints. Accordingly, the issue is how to choose the appropriate adhesive for the specific application relying on the properties of adhesive besides, the work conditions. This work deals with the experimental testing of four types of an adhesives that have been prepared to test by the two types of joints to comprehend the behavior of adhesives then choose the most effective and optimum type. The Butt and single lap joint tests were achieved according to the ASTM standard D2095–96 and D-1002-99 respectively. The adhesives that were used were epoxy Resins, MS Hybrid Polymers, Polyvinylester, and R.T.V Silicon Rubber, also, used a steel material as adherents. The study concluded important points about these adhesives and the recommendation suggested essential points to select satiable adhesive.

1. Introduction

Over the last decades, the bond strength of adhesive materials possesses a considerable deal of attention due to the development of manufacturing methods in different fields. This is field anticipated to expand further in the future [1-3], hence, the manufacture of adhesives has witnessed appearing on new adhesive materials that are compatible with new applications and technologies. However, despite the various types of these materials the main issue concerns how select the optimum type under different conditions of work.

The investigators Da Silva et al. [4] studied the effect of bond thickness on adhesive properties. The experimental results showed that the lap shear strength increases if the adhesive gets tougher and the thickness of the bond became thinner. Hayashida et al. [5] examined two types of specimens, double cantilever beam, and butt joint specimens via universal testing and drop weight impact machines. The results prove that fracture energy decreases with maximizing the rates of loading, also, behaves of adhesive were brittle. Besides, Goglio et al. [6] conducted that the strength of the adhesive is maximized with the strain rate increasing under a quasi-static test. Further, a study was done by Banea et al. [7], found that the lesser stress concentrations led to prefer the thinner adhesive layers relative to the thicker, and the ductile adhesive material probably work better with thicker adhesive layers as the energy can be absorbed more in a big volume. Campilho et al [8], shows the same principle can be regarded to the flexible adhesive material. Other investigators, Yokoyama and Shimizu [2] estimated the shear strength of adhesive joints under compressive impact via a specimen of a pin-and-collar.

An experimental study was done by Blackman et al. [9] investigated at two different temperatures the fracture energies of epoxy due to impact tests by using a high-speed servo-hydraulic machine. In the study [10] and [11] the researchers used the single lap joint as an important test to evaluate the adhesive bond. Adams and Harris [12] exhibited assessment of the adhesive joints under the impact test method by using finite element approaches. The result presented that the finite element analysis does not provide the strength data on adhesive joints for the application of engineering design. In the same approaches, Goglio

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and Rossetto [13], determined the mechanical properties of lap joints by applying the specimens to the impact loading, the study focusing on the thickness adhesive and reported that higher strength of joint could be accomplished by applying the impact loading relative to the static load, besides, they found that the thin layers of adhesive more useful compared to thick adhesive. Work is done by Kadioglu and Adams [14] discussed by using single lap joint (SLJ) the behavior of a flexible adhesive and steel adherents via pendulum impact machine. The study concluded that the lap joint strength increases under the impact test relative to the quasi-static test. The work achieved by M. Dziaduszewska et al. [15] the importance of butt-joint in adhesive tests effect of the thickness of adhesive to the stiffness. Breto et al [16] achieved a numerical analysis of the mixed adhesive joints. The result showed that the change of characteristics of the adhesive over the bond-line represents the impact factor to improve the performance of joints. Eventually, many investigators [17] used the butt joint test to study the epoxy resin and discuss the effect of the thickness of adhesive on the strength of the adhesive.

According to previous literature, the butt and single lap joint have represented powerful and important techniques that are used to study the behavior of different types of adhesives. Further, both quasi-static and dynamic loads can be used effectively to find the response of adhesives and adherents in various materials. On the other hand, can be noticed that a few researchers comparing the adhesives, especially the types that have been studied by this work. Consequently, the aim of this research is an evaluation and report the behavior of four conventional types of adhesives, hence, focused on the behavior of adhesives under quasi-static load with maintaining the thickness of the layer of adhesives, thus, can select the appropriate adhesive for the required applications.

2. Material of Adhesives

Four types of adhesives were chosen in this study: epoxy resins, modified-silane hybrid polymers, polyvinyl ester, and R.T.V silicone rubber. These adhesives are often used in many fields such as automotive, aerospace, and industry. Table 1 shows the general information about these adhesives. However, the adhesives can be presented briefly as the following:

Table 1: General properties of adhesives [22-25]

Adhesive	Tensile Strength [MPa]	Viscosity [mPa.s]	Density Mixture g/cm^3
Epoxy Resins	17	1000-15000	0.989
MS Hybrid Polymers	3.2	12000-55000	1.47
Polyvinylester	-	30-45	0.99
R.T.V Silicon Rubber	1.5	16000-10000	0.95

2.1 Epoxy resins

Epoxy material is considered one of the effective adhesives and is widely used as high implementation structural adhesives, especially in automotive and industry due to their capacity to cure without producing any volatile, besides, low shrinkage through curing [18, 19]. On the other hand, many studies have been discussed the epoxy-based applications of conductive adhesive [20]. The range of temperature of epoxy applicant is less than 200 ºC [21]. Hence, can be used in a wide range of applications. The trade name of epoxy that used in this study is (A-B-Yes Epoxy) and the appearance of these adhesives is shown in Figure 1.a, this epoxy consist of two parts; resin and hardener, however, these parts should be mixed before use at room temperature in the ratio of 1:1 by volume or also can be used the ratio 10:08 by weight [22].

2.2 Modified-silane hybrid polymers

Before 40 years ago, Japan developed MS Hybrid Polymers technology. Furthermore, the Soudal's company in Belgium perceives very early the usefulness of this technology, hence, they manufactured this type of adhesive for over 30 years. This technology is a patented exclusive and many advantages have been getten due to this type of adhesive such as high tensile and shear strength also good flexibility with a speed of cure from 3-24 hours [23]. Figure1.b shows the appearance of this material.

2.3 Polyvinylester

The traditional name of this Polyvinylester adhesive is (UHU All Purpose Adhesive), this synthetic adhesive is liquid resin and crystal clears as shown in Figure 1.c and used in universal applications, hence, it glues various types of materials faster and durably such as woods, plastics, metals, glasses, ceramics, fabrics, and papers. However, it is not suitable for polyethylene, polypropylene, and styrofoam. [24].

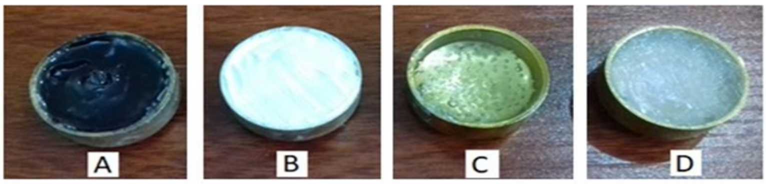


Figure 1: Appearance of different types of adhesives: (A) Epoxy Resins (B) MS Hybrid Polymers (C) Polyvinylester (D) R.T.V Silicon Rubber

2.4 R.t.v silicon rubber

Silicone Rubber is commonly used in general purpose applications. It is very good for exterior/ interior application on ceramic, vinyl, wood and glass...etc., however, it is applied in a variety of manufacturing implementations, this adhesive can cure at room temperature, besides, it owns low-temperature flexibility and good chemical resistance with excellent properties for electrical insulation. On the other hand, this product has a weak bond to organic rubber [25]. Figure 1.d shows the appearance of R.T.V silicon rubber material.

2.5 Material of adherend

To avoid any plastic deformation or substrate failure in the adherent, steel material has been used to manufacture two types of specimens according to the type of joint and direction of the load. However, it is wise to be sure of the type of the adherent before any preparation of specimens to test.

3. Configurations of Specimens

3.1 Butt-joint test

The butt-joint tests are widely used in the aerospace and automotive industries [26]. These specimens of the test correspond with ASTM Standard (D2095 – 96) [27]. Two discs with a diameter of 22 ∓ 0.3 mm of steel was used on the specimen and the glued material was put between these discs. Figure 2 shows the dimensions of these specimens and the direction of the applied load.

3.2 Single-lap joint test

Many industrial applications used a single-lap joint in tests [4, 28]. The specimen of single-lap joint configuration corresponds with ASTM Test Method (D-1002-99) [29]. All the dimensions of steel plates that are used in the shear test are shown in Figure 3. with the direction of the force. However, the thickness of the plate of the specimen was 2 ∓ 0.2 mm.

4. Manufacture of Specimen

4.1 Specimens preparation

Two kinds of the experimental setup are utilized in this work, the adherence was made of steel with a thickness of 2 mm and four types of adhesive materials were utilized. All the properties of the adhesively bonded were recorded under a quasi-static test. Furthermore, useful auxiliary instruments have been used to fix and adjust the specimens. The adhesive joint for a metal plate such as steel or aluminum materials is the most common due to the simplicity and efficiency in the process of manufacturing the specimens of butt and single lap joint. The strength of the joint could be influenced by many factors such as the kind of adhesive, the kind of adherent, the thickness of the bond layer, and the length of the overlap.

The tensile and shear tests were achieved by using butt-off and single lap joint specimens. Bolt and small disc were prepared to manufacture the Butt- joint specimens, the out surfaces of the discs were cleaned and flatted. After preparing the adherents, the adhesive has been placed between these flat surfaces of discs and plates at room temperature 25-26 $°C$. Furthermore, all the specimens were prepared according to the ASTM standard. Figure 4 shows all the steps to preparing the adherent.

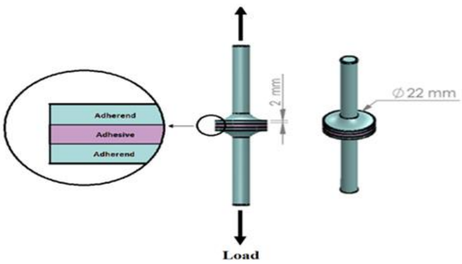


Figure 2: Butt-joint specimen

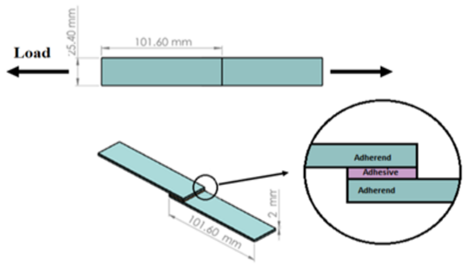


Figure 3: Single laps joint specimen

Figure 4: Manufacture and prepare the adherent

To prepare samples for testing, two types of instruments have been used to grip and adjust the specimens. Figure 5 shows the auxiliary instruments in this study. The instruments on the left were used to tighten and adjust the Butt- joint before the tensile test. On the other hand, the thickness of the adhesive layer in both types of specimens (butt-off and single-lap joints) has been controlled via the instruments that are shown on the right side.

All dimensions of specimens must be adjusted to maintain the dependable work from these tests. Moreover, the same procedure has been done in the plates of single lap joint specimens. Figure 6 shows the butt-off and single lap joint specimens, the thickness of the adhesive layer was 2 ± 0.1 mm. However, after two to three weeks the specimens have been tested.

4.2 Experimental procedures

The Universal Testing Machine has been used in this study, this machine uses a servo-hydraulic load or servo motor system controlled by a computer. The equipment such as extensometer, encoder, and load cells, used to obtain the test values such as load, displacement, and extension, this mode is controlled by a three close-loop. The accuracy reaches $\pm 1\%$ with high reading resolution and speed control from 0.01 to 500 mm/min. Figure 7 shows this machine [30].

Figure 8 shows the instrument that was used to fix the butt-joint specimen via the grip screws and adjusting the specimen with the loading axis, further, displays the single lap-joint test. The experimental work was conducted at a constant speed rate of 1 mm/min using the servo-hydraulic machine. Force and elongation up to failure were reported. Two joints were tested up to failure for each type of adhesive. However, this procedure has been used to examine all types of different specimens.

5. Results and Discussion

The relationship between the normal force and elongation of the butt and single lap-joints have been recorded graphically after appling quasi-static tensile load. Furthermore, displayed the surface morphology after failures for each type of specimen and has been indicated inside these plots, however, the average thickness of the adhesive layer remains 2 mm for both types of joint in all specimens.

The first observation of the behavior of epoxy resin in all tests is the net brittle properties of this adhesive. However, the tensile force for epoxy resin has the highest value in both butt and single lap-joint of tests 968 N and 749 N respectively, with more sensitivity to the elongation (the lowest value) 1.02 mm and 0.664, as shown in Figure 9 a and b. The fracture surface in the same figure indicates the adhesive and interfacial failure mode in both tests due to the delamination between the adherents and the adhesive layer of the specimen. In fact, these results compatible with several studies [31-33], proved the high strength of epoxy bonds in a different application. As shown in Figure 10, the MS hybrid polymers deformed plastically with increasing about 284% (2.9 mm) in elongation, besides, reduction in normal force about 55.5 % (537N) relative to the epoxy resin due to the ductility of this adhesive. On the other hand, the same behavior of ductility appears in the overlap of the joint. Hence, the elongation maximizes about 584% (3.88 mm) and the sheer force reduction about 65.5% (492 N) relative to the epoxy resin, however, Figure 10.b indicates this behavior clearly. All the previous results identical with other works [34, 35] proved the good properties of MS hybrid polymers. After examining the morphological of surface which offered in Figure 10. a and b, the cohesive failure mode has been appeared mainly in both tests, further, the adhesive failure mode recorded in the overlap of the joint, substantially, these modes of failures appear due to the ductility and high plasticity of this material.

Figure 5: The Instruments that use to adjust the thickness of adhesive material in specimens

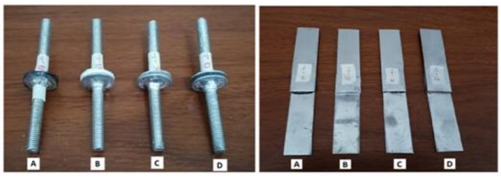


Figure 6: The specimens of butt-off and single lap joint

Figure 7: The universal test machine

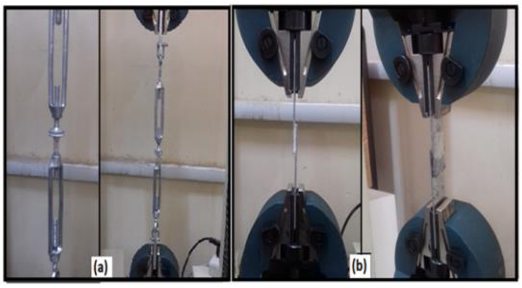
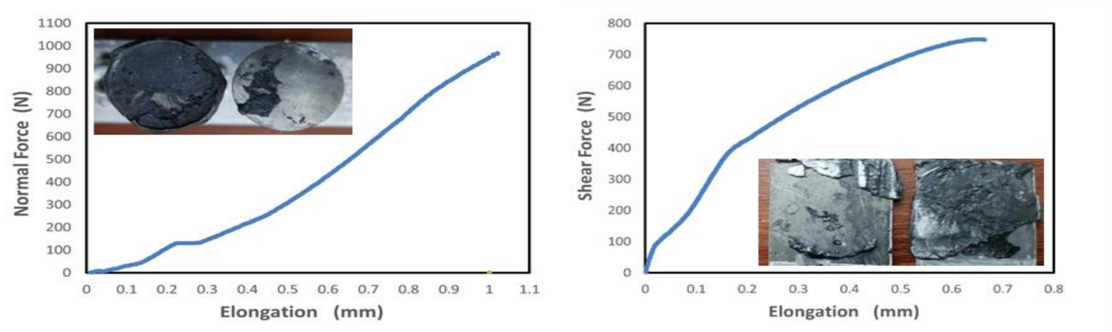
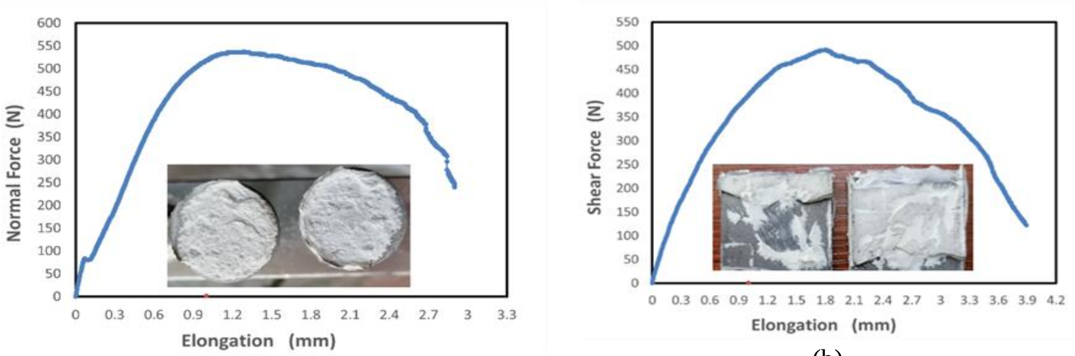


Figure 8: Specimens under quasi-static test (a) butt joint (b) single lap joint



(a) (b)

Figure 9: Typical curve for epoxy resin: (a) Normal force – Elongation, (b) Shear force – Elongation



(a) (b)

Figure 10: Typical curve for MS Hybrid Polymers: (a) Normal force – Elongation, (b) Shear force – Elongation

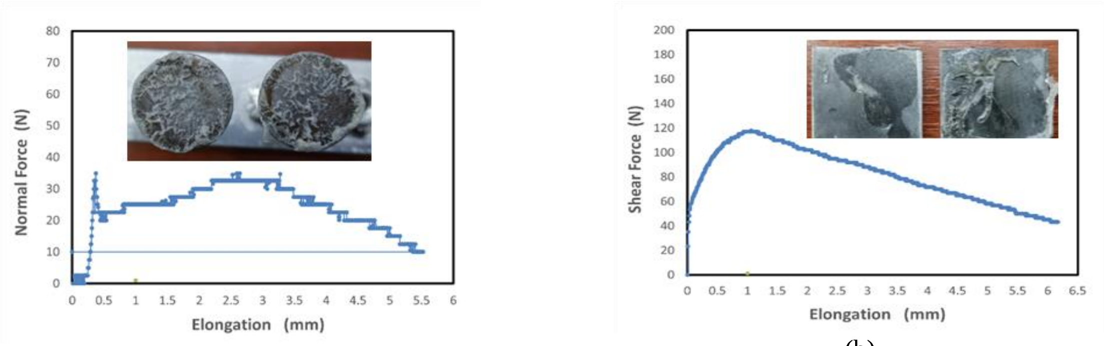
The overview of the load-displacement diagrams for the specimens of polyvinyl ester indicated obviously the elastic behavior of this adhesive, this response led to a significant increase in elongation 5.52 mm, but unfortunately, the high deterioration in the force has been occurred, hence, the magnitude of force decreases to the lowest value as compared to adhesives (under butt-joint test) and reached to 35 N, as shown in Figure 11.a. The value of shear force and elongation of polyvinyl ester was 118 N and 6.17 mm respectively in the overlap of joint, the elasticity of material confirmed the ductility behavior of adhesive, however, the experimental data of single lap-joint described that in Figure 11.b. The morphological surface offers the pure cohesive failure in the butt-joint test with mix mode (interfacial with cohesive failure) in the overlap-joint test, as shown in Figures 11.a and b.

The results of R.T.V silicon rubber tests displayed an increase of elongation and reach to the high value and nearest to the MS hybrid polymers, but, it stays less than the magnitude of polyvinyl ester and were about 2.5 mm and 3.7 mm in the butt and single-lap joint respectively, Figure 12.a and b showed this behavior. The obtained values in the butt and single-lap joint were 89 N and 100 N respectively, and can be seen in Figure 12.a and b. Hence, the normal and shear force is less than the epoxy and MS hybrid polymers conversely the polyvinyl ester, Additional, the mode of failure after the adhesive test was mixed between an interfacial and cohesive mode in single lap-joint test with cohesive failure in the butt-joint test.

Three types of failure modes can be seen after the result of tests of various joints, a cohesive failure mode that occurs within the adhesive and that refer to the strength of the bond between the glue material and adherent, on the other side, the adhesive and interfacial failure occurs at the interface (between the adhesive and adherent) and that mean weakness of bond in the joint.

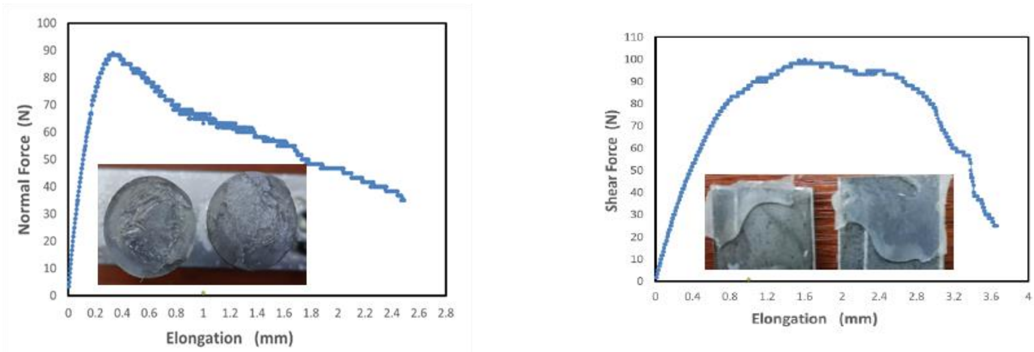
Figure 13a and b display the comparison between these adhesives according to two types of parameters (force and elongation) in both butt and single lap joints. Consequently, the peak value of normal and shear force can be observed in epoxy resin, conversely, the minimum value can be found in polyvinyl ester in the butt-joint test and the R.T.V silicon rubber in a single lap-joint. On the other hand, the polyvinyl ester presented the peak value of elongation, and the minimum value was obviously noted in epoxy resin. The favorable properties can be observed in the typical curves of MS hybrid polymers if comparison with rest curves as shown in Figures 13a and b. However, it combines strength and flexibility with a moderate value if compared with the remainder.

Statistically, both Figures 14. a and b with Figure 15 a and b can be considered the best way to identify all values of strength and elongation, further, can be summarized in Table 2.



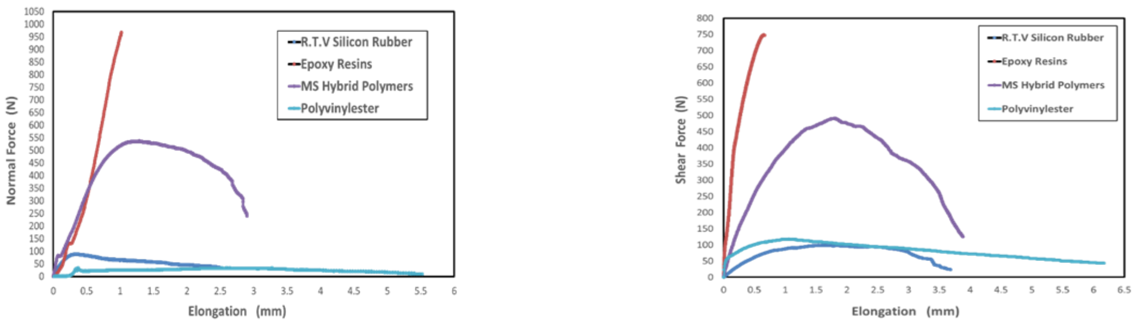
(a) (b)

Figure 11: Typical curve for Polyvinylester: (a) Normal force – Elongation, (b) Shear force – Elongation



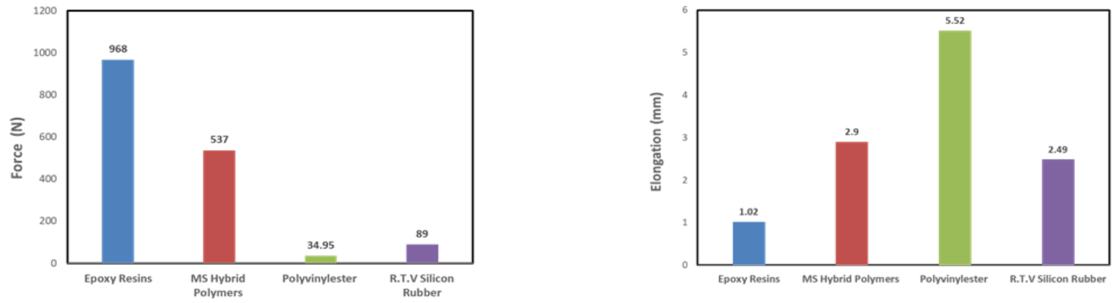
(a) (b)

Figure 12: Typical curve for R.T.V Silicon Rubber (a) Normal force – Elongation (b) Shear force – Elongation



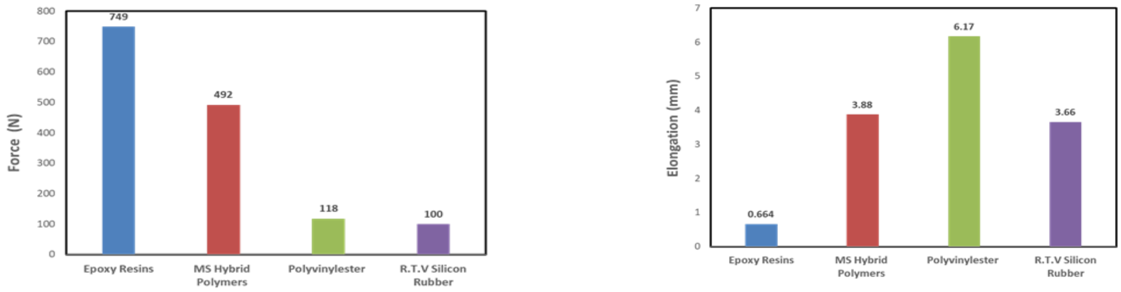
(a) (b)

Figure 13: Force – Elongation curve of various types of adhesives (a) Normal force (b) shear force



(a) (b)

Figure 14: Comparison between adhesives in butt-joint test (a) Normal force (b) Elongation



(a) (b)

Figure 15: Comparison between adhesives single lap-joint test (a) Shear force (b) Elongation

Table 2: Comparison between adhesives

Adhesive	**Butt-joint test**		**Single lap-joint test**	
	Normal Force	***Elongation***	***Shear Force***	***Elongation***
Epoxy Resins	Max	Min	Max	Min
MS Hybrid Polymers	Moderate	Moderate	Moderate	Moderate
Polyvinyl ester	Min	Max	low	Max
R.T.V Silicon Rubber	low	Moderate	Min	Moderate

6. Conclusions and Recommendations

All the modern industries generally employ adhesive bonding in their manufacture and day after day is getting wider. Consequently, the adhesives should have a lot of efficient properties including enhancing the mechanical and chemical properties, as well as, increasing the strength of the adhesive to the shear and normal loads, also, increasing the resistance to solvents and high temperature conditions.

This work deals with experimental testing of four types of conventional structural adhesives and a comparison between these adhesives by using two types of joints under quasi-static conditions. Based on that, the comparison has been done according to substantial parameters such as applied load, elongation, the behavior of the material and failure mode.

The evaluation of adhesive in this article essentially depends on the ability of adhesives to transfer the applied force or absorb the energy, besides, maintain the strength of the bond of joint with the suitable flexibility, however, can be summarized conclusions by the following points:

1) Epoxy Resin: The behavior of this adhesive refers to brittleness with high strength under normal and shear loads, the failure mode essentially is an adhesive failure, hence, recommend to use this adhesive in inflexible applications that need a strong bond.
2) MS Hybrid Polymers: This adhesive owns the ductility properties (increasing in elongation about 284% and 584% relative to epoxy resin in the butt and single lap joint, respectively) besides good strength to the normal and shear forces, the failure mode was a cohesive failure due to strength of the bond to the adherend, thus, this type of adhesive is suitable for employ in the high range of applications which need reasonable strength bond with flexibility.

3) Polyvinyl ester: the result shows a weak bond to high load of normal and shear loads, but at the same time have the significant elasticity (relative to the epoxy resin the elongation increasing about 441.2 % and 829.2 % in the butt and single lap joint, respectively), the cohesive failure mode means a good bond to an adherent, however, using of this adhesive restricted to the low value of the applied load.
4) R.T.V Silicon Rubber: This type is the most conventional adhesive that has been used in many applications with high flexibility (elongation was increased about 144.1 % and 454% compared to epoxy resin in the butt and single lap joint respectively), but unfortunately, it can't withstand the high load. The mode of failure was mixed between interfacial and cohesive modes. The study recommends using this adhesive in parts that work under low or moderate loads with high elasticity.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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