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Research Article

Design and Manufacture of a Device to Determine Shear Force in Adhesive in the Interpretation of Metal-To-Metal Bonding Under ASTM D1002-10

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ABSTRACT

This study focuses on the design and manufacture of a specialized device to measure the shear force in adhesive joints, with emphasis on the interpretation of the metal-metal joint. The practical application of the device involves the bonding of a square tubular profile (PTR) to an aluminum specimen using an epoxy adhesive specific to steel joints.

The design of the device focuses on creating a system capable of applying an axial load and measuring the shear force required to separate the PTR and the aluminum specimen. The geometry of the parts to be joined, the load distribution and the ability to reproduce realistic force application conditions are considered.

The manufacture of the device is carried out with precise techniques to ensure the accuracy and reliability of the results. Strong and durable materials are used to ensure the structural integrity of the device during multiple tests.

The experimental procedure involves the preparation of the bonding surfaces, the application of a steel-specific epoxy adhesive and the attachment of the PTR to the aluminum specimen. The device is then used to measure the cutting force required to separate the parts.

The results obtained are analyzed to determine the effectiveness of the adhesive in metal-to-metal bonding. Factors such as adhesive strength, cohesion between metal surfaces and the influence of geometry on shear force are considered.

Keywords: Generalized Intuitionistic Trapezoidal Fuzzy Numbers, Transportation Problems, Optimization, Linear Programming, fuzzy ranking

INTRODUCTION

Due to the changes that arise in the industry as well as in particular circumstances, solutions are always being sought, so adhesive joints open interest or demonstrate ease about the pros they have compared to other types of mechanical joints. Only that by not being so new or not providing that security, its applications are too limited since they are never used in structural joints such as fastening, support or leveling. This seeks to expand the use of this type of material much more. For this reason, the joints or adhesive joints, in this case metal-to-metal, consist of a resistance, which can be measured with a test base manufactured by CNC where aluminum samples of certain dimensions were mounted, which will be adhered to a square tubular with the surface untreated (unsanded), with the surface treated (sanded) and with the addition of a rubber in this type of joints.

Therefore, these specimens will be subject to shear stresses in order to predict the failure stage and the feasibility of their application as such with the help of our stress deformation diagrams and mathematical analysis.

Justification

The main objective of the proposed research is to comprehensively and scientifically address the problems related to the failure analysis of adhesives used in metal-to-metal joints under shear stress in the Shimadzu AG-IC universal testing machine. The growing demand for industrial applications requiring these types of bonds has led to a need for a thorough understanding of the mechanical properties of the adhesives used, with a special focus on their toughness and fracture energy. In conclusion, this research paper addresses a critical need in the field of metal-to-metal and adhesive bonding, offering valuable insight for material improvement and the design of more robust and durable structures. Implementing a test base provides a solid platform for obtaining reliable data, thus contributing to the advancement of materials science and structural engineering. In itself, a failure analysis of an adhesive subjected to a tares or shear stress will be carried out, implementing a test base, to check its toughness and fracture energy that it has to know if the metal-metal bond is viable. This research was conducted under **ASTM D1002-10.**

1.Objectives

- Determine the Adhesive Shear Stress Resistance:

Quantify the adhesive's ability to resist shear stresses and evaluate its behavior under these specific conditions.

- Implement a Representative Evidence Base:

Develop and use a test base that accurately simulates the actual operating conditions in which metal-to-metal joints are found, ensuring the validity and applicability of the results.

- Compare Different Types of Adhesives:

Investigate and compare various types of adhesives in terms of their toughness and fracture energy under stress shear, with the goal of identifying those that demonstrate optimal performance.

- Foster Innovation in Bonding Materials:

To stimulate innovation in the design and development of new metal-to-metal bonding materials, leveraging research findings to drive breakthroughs in the field.

1.1.General

- Achieve the determination of adhesive strength by shear stress.

1.2.Particular

- To be able to obtain the necessary force for the detachment of the adhesion between the materials in question, which are steel and aluminum, and to verify the reliability that what they offer us in the market is correct, all this in accordance with the corresponding ASTM standards by means of the shear stress test.

2.BACKGROUND OR STATE OF THE ART

2.1.What is an adhesive?

The term "adhesive" refers to a substance capable of joining two or more objects by contact on their surface, being synonymous with glue and glue. Its relevance in contemporary industry is significant.[3]

The use of adhesives dates back to ancient times, and bonding was arguably the first method of long-lasting bonding. Today, adhesives are used in a variety of applications to bond and seal similar and diverse materials, including metals, plastics, ceramics, wood, paper, and cardboard.

The most relevant adhesives in the field of engineering are structural adhesives, which have the ability to establish solid and durable bonds between strong and rigid bonded parts. There is a wide variety of adhesives available on the market, which harden through various mechanisms and are suitable for bonding various materials.

2.2.How are adhesives classified?

The classification of adhesives is given as follows:

- Natural.

- Inorganic.
- Synthetic.

Natural:

Natural adhesives come from natural sources, such as plants and animals, and include substances such as gums, starch, dextrin, soy fluoride, and collagen. These types of adhesives are often used in low-demand applications, such as cardstock, furniture, and book binding, or in situations involving large surfaces (e.g., plywood). [1]

Inorganic:

Inorganic adhesives are mainly based on sodium silicate and magnesium oxychloride. Despite being cheaper, their strength is also more limited, which constitutes a serious restriction in structural adhesion applications.[1]

Synthetics:

Synthetic adhesives are the most significant category in manufacturing, encompassing various thermoplastic and thermoset polymers. Many of these polymers are briefly detailed and described, and their curing process is carried out by various mechanisms, such as: 1) mixing a catalyst or reactive ingredient with the polymer just prior to application; 2) heating to initiate a chemical reaction; 3) healing with radiation, such as ultraviolet light; and 4) curing by evaporation of water from the liquid or paste adhesive. Additionally, some synthetic adhesives are applied in the form of films or as pressure-sensitive coatings on the surface of one of the bonds.[1]

Table 1.- Types of synthetic adhesives.[2]

Adhesive	Description and application
Anaerobic	Crafted from acrylic, this single-component thermoset adhesive hardens using a free radical mechanism at room temperature. Its uses include functions such as sealant and structural assembly.
Modified Acrylics	This adhesive, which is thermoset and two-component, comprises an acrylic resin and a initiator/hardener. Experience the curing process at room temperature after mixing. It is used in applications such as bonding fiberglass on boats and metal sheets on vehicles and aircraft.
Cyanoacrylate	Made from acrylic, this single-component thermoset adhesive hardens at room temperature on alkaline surfaces. Its uses include bonding rubber to plastic, electronic components in circuit boards, and plastic and metal packaging for cosmetic products.
Epoxy	It comprises a diverse range of widely used adhesives, developed from epoxy resins, curing agents, and fillers/modifiers that undergo the hardening process after mixing. Some of these adhesives cure by heating. They are applied in various functions, such as bonding aluminum and honeycomb panels in aircraft, reinforcing metal sheets for automobiles, laminating wooden beams, and seals in electronic devices.
Heat melted	A single-component thermoplastic that hardens from a melting state when cooled from elevated temperatures. It is formulated with thermoplastic polymers encompassing ethylene vinyl acetate, polyethylene, styrene block copolymer, butyl rubber, polyamide, polyurethane, and polyester. Its applications include use in packaging (such as containers and signs), furniture, footwear, book binding, carpet installation, and assemblies in electrical products and automobiles.
Pressure-sensitive tapes	They are typically pressure-receptive and are composed of a high-viscosity solid component,

and films	resulting in a bond when pressure is applied. They are composed of several high molecular weight polymers and can present the adhesive on one or both sides. They are used in various applications, such as solar panels, electronic assemblies, plastics for wood and metals.
Silicon	It is a thermofixed fluid, either one or two components, made from silicon polymers. It hardens at room temperature forming a solid rubber. It is used in various applications, such as seals on vehicles (such as windshields), seals and insulation on electronic devices, packaging, and the bonding of plastics.
Urethane	Thermoset adhesive, either one or two components, formulated with urethane polymers. It is used to bond fiberglass and plastics.

2.3.Difference between adherence, adhesion, cohesion and coherence.

Adhesion refers to the forces that oppose the separation of molecules belonging to different bodies, with "adhesion" being the resistance to the separation of different materials. In contrast, "cohesion" describes the union between molecules within the same body, indicating the resistance to the separation of molecules into a homogeneous entity. On the other hand, "coherence" is defined as the forces that prevent the separation of molecules in a heterogeneous body.

It is essential not to confuse the terms 'accession' and 'cohesion'. Both cohesion and adhesion are defined by the relationships between molecules, with cohesion applicable to molecules within the same body and adhesion to molecules from different bodies.

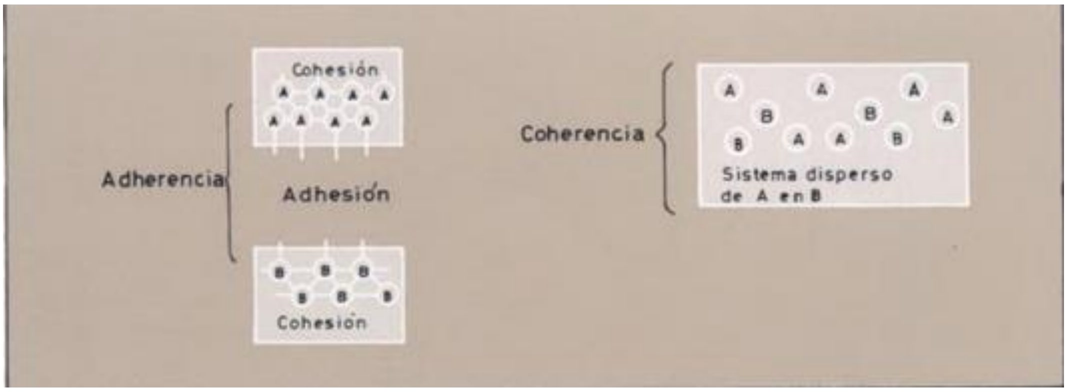


Figure 1.- Illustration of differences between adhesion, cohesion and coherence.[2]

An illustrative example would be to take two pieces of natural rubber: when kneaded together, they form a single body, which is called "dough cohesion". However, if we apply one against the other, the concept changes to "adhesion".[2]

Therefore, due to the constant changes to which we are not too accustomed on a daily basis, adhesive joints or joints open an important way for us as alternatives are sought to minimize costs or hours of work in production, therefore making a watershed with the issue of adhesives keeps us with a somewhat defensive posture for the simple fact of not generating the same efficiency of a mechanical bonding, but as AJ Kinloch mentions in his article "it not only depends on the adhesive but also on certain parameters such as: the type of joint design and exact geometric configuration". Also an important part that must be taken into account is the adhesive fracture energy since it is a non-linear function in terms of the thickness of the adhesive layer. Where it was explained by Kinloch that due to the magnitude of plastic dissipation in the adhesive layer depends on the degree of restriction which is supported by Huston.[4] Therefore, something vital that becomes the object of research is the toughness or resistance found in the material, since it will depend not only on the significant parameters mentioned above, but also on the type of sample that is used at the time of testing with the variety of specimens subjected in a shear stress, contributing to studies previously carried out by Pardon.

3.DESIGN

Due to the little precedent that there is on adhesive tests with applications in structures, it is encouraged based on brainstorming to use a proposal of a fixture, with which it would be possible to obtain a metal-to-metal union to scale, in which it would be established to be able to subject an adhesive to shear stress, since this favors us enough to obtain theoretical validation results. See in more detail the characteristics of the material carried out in the tests as adhesives, or how they behave in the different metals that exist, also the variability of materials such as the properties and guarantee confidentiality and consistency in the adhesive or metal. Then come the simulated service conditions, since the tests allow to simulate the real conditions to which the joint will be subjected in the practical application, in congruence also the optimization of design and finally and most importantly the guarantee of quality and safety, that the tests provide an empirical basis to evaluate the quality and safety of the joint. A detailed understanding of the mechanical properties and fracture resistance of the adhesive helps to ensure that the bond meets the required standards and is safe under service conditions. And that is why this research design was chosen to execute the tests and its easy maneuverability and adaptation.

The number of elements used for the test in question was 8:

1. Plate (Steel 1045 cold roll)

This will be used to give better rigidity to the evidence base of the suggested analysis

2. Bucket - PTR 3x3" (Steel)

This will be the material to which a light layer of adhesive will be glued while centered on the aluminum test base.

3. Screws 8 mm (steel)

These screws will serve to give you complete rigidity and coupling on the shear stress testing machine.

4. Screws 6 mm (steel)

These screws will serve to hold the support of the test base as well as the board firm.

5. L bracket (steel)

These supports will serve to keep the PTR anchored and rigid to the base plate to be able to handle it and carry out this load on the specimen with the shear effect

6. - Adhesive (Epoxic gorilla)

This component will have the purpose of joining aluminum and steel, which will be subjected to axial forces during the bond test.

7. Awl.

This will have the primary purpose of effecting the main load on the test aluminum and subjecting it to the structural failure of the adhesive itself.

8. 1x1" sample. (Aluminum 6061)

It will be the main exhibition where it will have adhesive in the joint, to have a union between aluminum and steel.

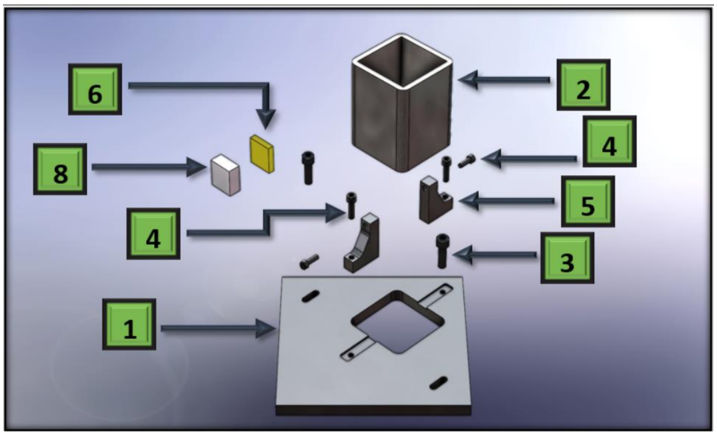


Figure 2.- Exploded view of the metal-to-metal bonding test base.

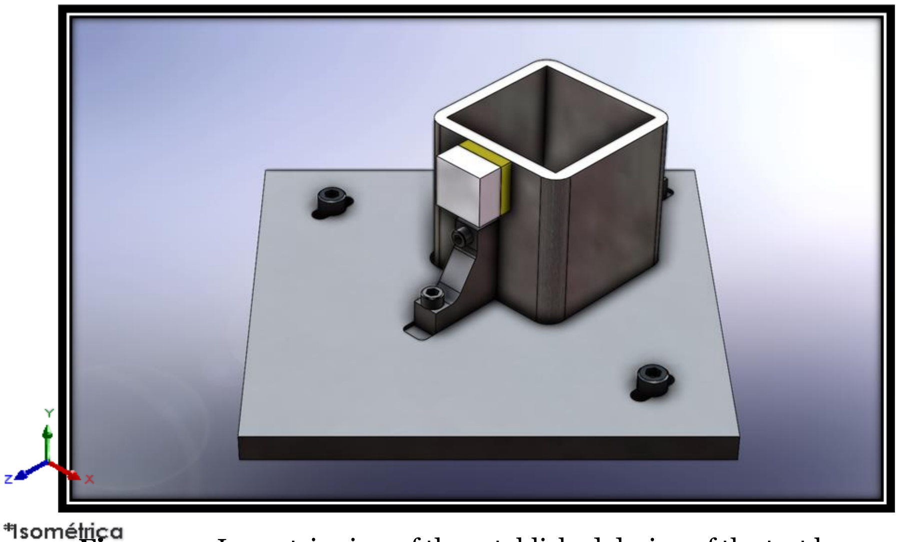


Figure 3.- Isometric view of the established design of the test base.

3.1.PLANS

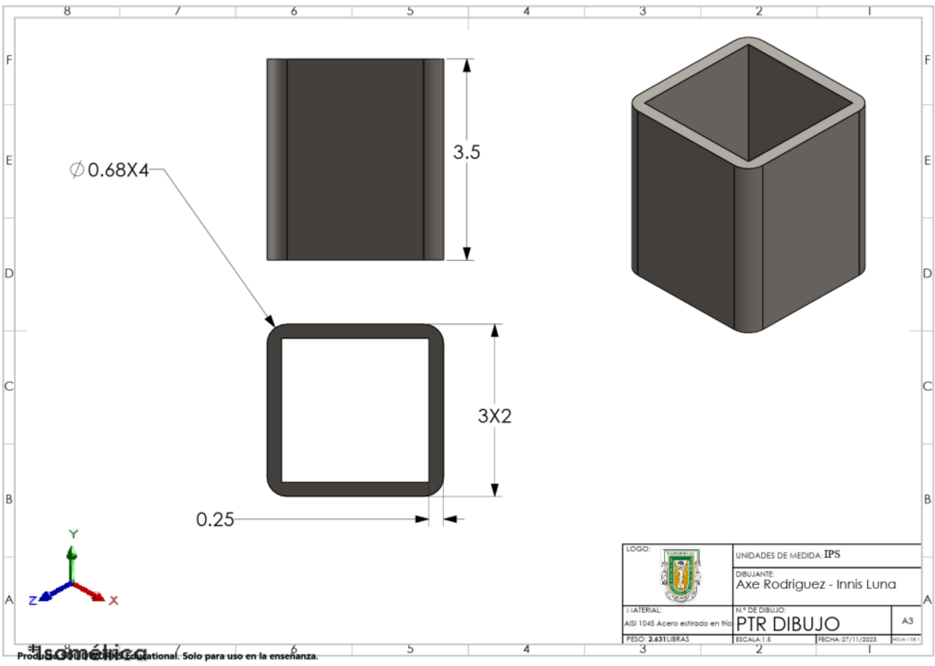


Figure 4.- Representation of the plan of the PTR used with its respective parameters.

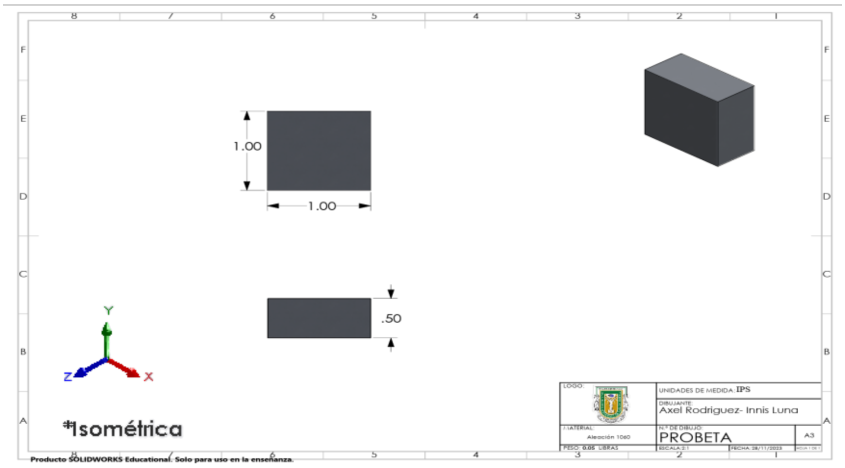


Figure 5.- Representation of the plan of the aluminum specimen used with its respective parameters.

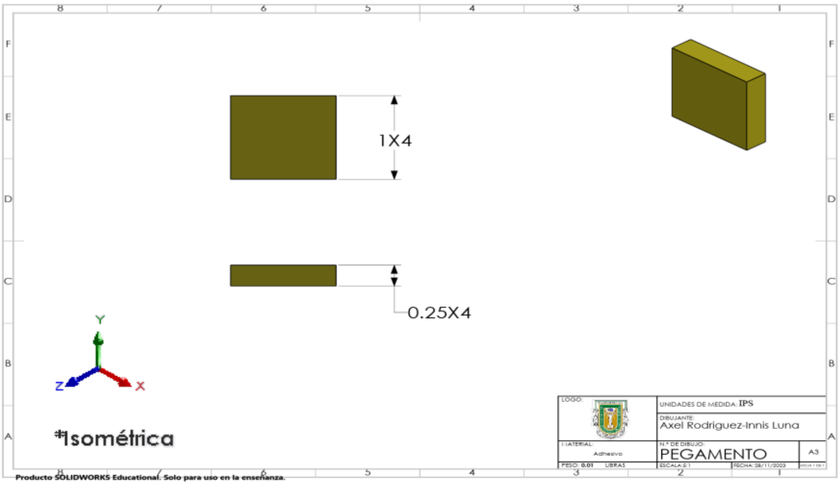


Figure 6.- Representation of the plane of the adhesive used with its respective parameters.

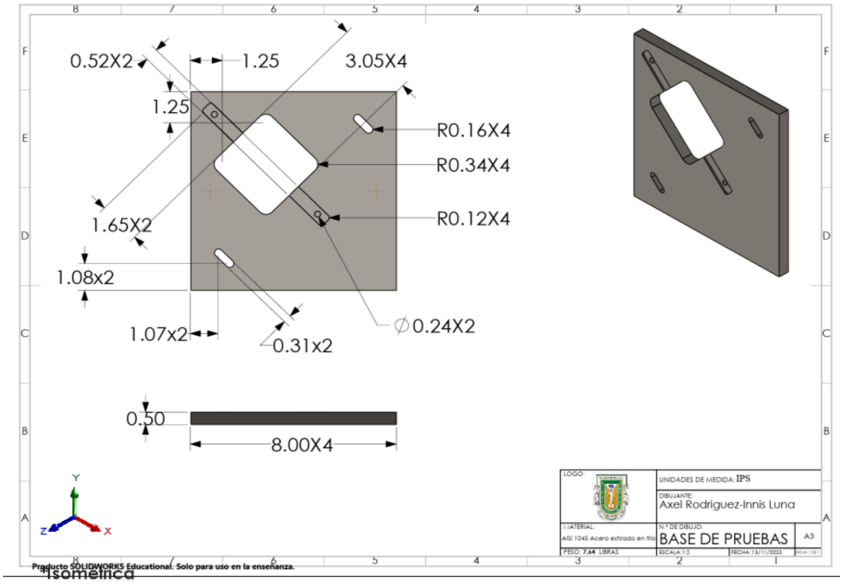


Figure 7.- Representation of the plan of the steel plate used with its respective parameters.

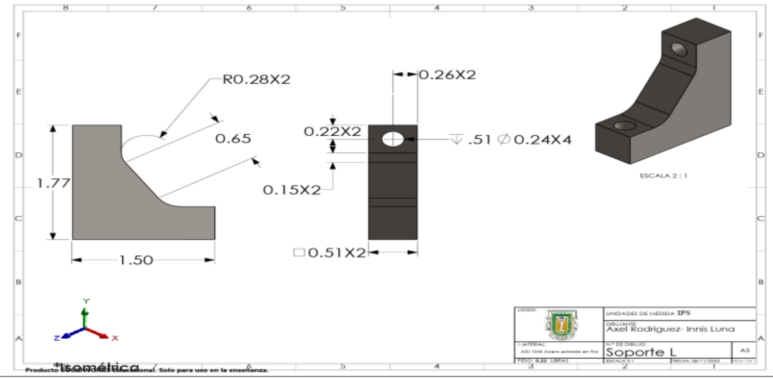


Figure 8.- Bracket that holds the PTR fixed to the motherboard.

4.EXPERIMENTAL DEVELOPMENT

- **Fixture machining for testing.**

Above the above, for the manufacturing process of the device for testing, first, the idea is generated due to the application for support and leveling of a company, which opens the way to have a vision in the part of structures with the concept of "innovating" some mechanical joints. For this reason, it is possible to generate this device based on CNC machining with the milling process.

This process is made up of two stages and with the help of the Mastercam X5 software it exposes all the necessary parameters to generate the cuts, holes, among other operations that will be exposed below.

➢ ***BASE***

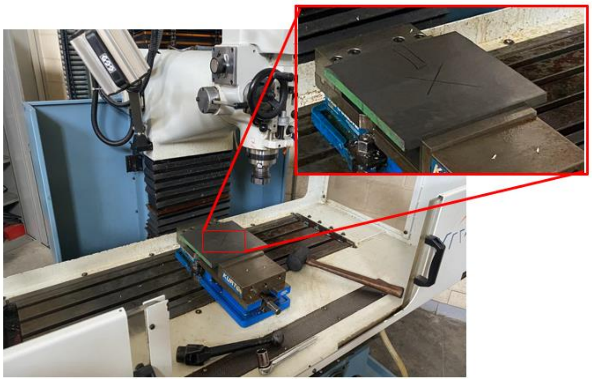
For the first part of the machining process, it begins with the base, which is a square piece with the following dimensions:

✓ 8" wide x 8" long of rolled-colled material.

✓ 1/2" thickness.

As can be seen in the part in Figure 9, it starts with the grinding part of one of the side faces and then the center of the part is found to generate the necessary drawings and be able to make the set up prior to machining. In our case, an opening will be made to be able to insert the tubular (PTR) with the dimensions 3" x 3", where a 3/8" 4-edge cutting tool was used, in addition to this, two grooves (figure 10), where it was started with a hole passed 8mm in diameter and a length of 1", this to have a positioning margin when securing the plate for the shear test. To carry out this hole, a 0.3160" Ø drill bit was used for the fasteners that will be in the universal testing machine.

On the other hand, in order not to produce any free movement in the L-type supports, a small indentation or channel was made, in which the bra for the tubular will be inserted, this has a length of 1.65 inches with a width of 1/2 inch (figure 11).



a)

(b) (c)

Figure 9.- a) Center of the part b) Start of opening machining for PTR, c) Finished opening.

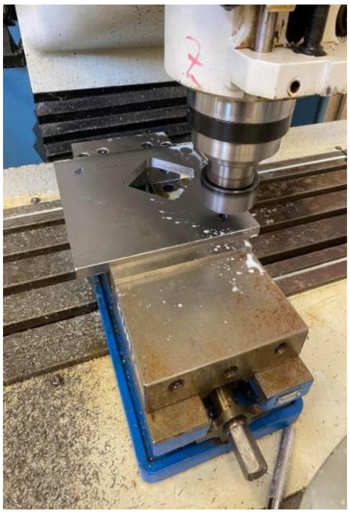


Figure 10.- Grooving process.

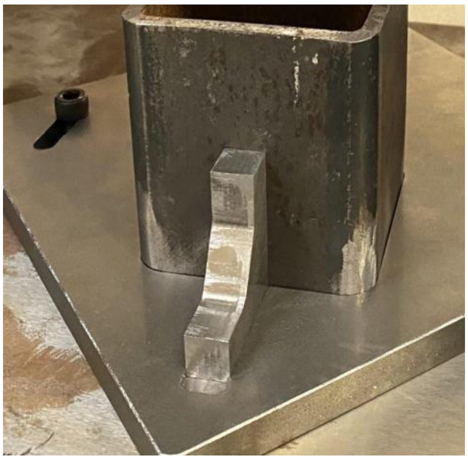


Figure 11.- Slit for L-type support.

- **L-BRACKET**

In the case of the L-type side supports, a 3" x 6" slab was used, making a diagonal cut, in which a sketch was made in it (figure 12). Following this, it is given its respective measurements, with a height of 1.77 inches and a length of 1.50 inches, a cut of the excess is made with the intention of being able to make a successful grip on the milling machine press (figure 13). In addition to the primary cuts, two passed holes were also made with a measurement of 1/4 inch with the function of securing the L with the base of the test device and the other hole with its respective rope to hold the tubular with the screws and prevent it from moving and disturbing the measurement (Figure 14).

Figure 12.- L-type anchor sketch.

Figure 13.- Surplus cut.

Figure 14.- L-type anchorage.

- Adhesives to use.

In order to carry out the adhesive testing process, an epoxy adhesive was used: (Figure 15):

Figure 15.- Epoxy adhesive

- Adhesive preparation.

Adh. Epoxy: in the case of this adhesive it has two products, which are the resin and the catalyst or hardener, similar proportions are mixed until it turns with a grayish hue, the application is made with tongue removers leaving a film on the study sample, pressure is applied directly with the hands or with the help of a clamping tool such as C presses or clamps, excess is cleaned and allowed to cure to be more effective in the application of the adhesive. On the other hand, it must be taken into consideration that you have *less than 10 minutes to handle the* adhesive before it reaches its gelling point.

- Adhesive curing.

Adh. Epoxy: Once the aluminum sample with adhesive has been correctly placed in the PTR, we will proceed to wait ideally 24 hours for the adhesive to cure, the time will depend on the information provided by the manufacturer in question and thus be able to perform the shear tests on the universal testing machine.

- Parameters for adhesion.

In this section, four aluminum specimens and the central part of two sides of the PTR were sanded, while the other two were not sanded. This was done to check for adhesion differences in different tests and allow the adhesive to cure for the specified time.

- Fixture installation.

In the installation process, the first thing that was done was to assemble the test device to be able to carry out the shearing effort. The punch was used to place the 8x8-inch steel plate on the test base of the Shimadzu machine and center the aluminum specimen to the punch. 8mm screws were then placed to secure the plate to the test base. Subsequently, the PTR was placed with the aluminum specimens already adhered and cured in the corresponding hole, and the steel L supports were placed so that the PTR would be solid to the base. Then, the fixing holes of the supports were screwed with 6mm screws to keep the test base solid, and it would be ready for the execution of the shear test to be carried out.

Figure 16.- Test device.

- Shear test.

To carry out the test in question, the installation is previously made where two 2 elements will be involved, which are the sample with the glue and the punch. The punch will act axially, which will generate a shear stress on the upper surface of the sample, thereby detaching the PTR surface and in turn measuring the resistance of the glue.

5.RESULTS

The results presented by the tests of the 4 tests that are handled, it must be taken into account that the surfaces to which the samples adhered, two of them were sanded and the other two were not, so only 3 of them presented "satisfactory" results, these were the ones that showed the best results in the study effort.

Figure 17.- Essay #1.

Below is a table with the results corresponding to each sample made with the epoxy adhesive:

Table 2.- Results obtained by the shear stress test.

Test	Resistance (N)
1	11812.5
2	16709
3	11231.3
4	7837.5

As soon as the results can originate few or quite a few differences, it depends on the variations that we are handling or what parameters are imposing to make each sample the object of study.

6.Analysis of results

Given the results of each of the tests, a greater resistance to shear stress was demonstrated, in test number 2 with a force of 16709 newtons, from that force the calculation of maximum shear stress is obtained:

$$\tau = \frac{VQ}{It}$$

$$V = 16709.4\ N$$

$$Q = A \cdot \bar{y}$$

$$A = 5.08x10^{-4}\ m^2$$

$$\bar{y} = 0.0127\ m$$

$$Q = (5.08x10^{-4}\ m^2)(\ 0.0127\ m)$$

$$Q = 6.45x10^{-6}\ m^4$$

$$I = (0.0254\ m)(0.0254\ m)^3$$

$$I = 4.16x10^{-7}\ m^4$$

$$t = 0.0254\ m$$

$$\tau_{max} = \frac{(16709.4\ N)(6.45x10^{-6}\ m^4)}{(4.16x10^{-7}\ m^4)(0.0254\ m)} = 1.0152x10^7\ Pa$$

Figure 18.- Calculation memory for maximum shear stress

With the other 3 remaining tests, they described results with lower stresses than test number 2 with results ranging from 7837 to 11812.2 newtons, this due to the parameters that were established, which were not to treat the surfaces (sand) in order to create variations and have comparisons of results in terms of treated and untreated surfaces.

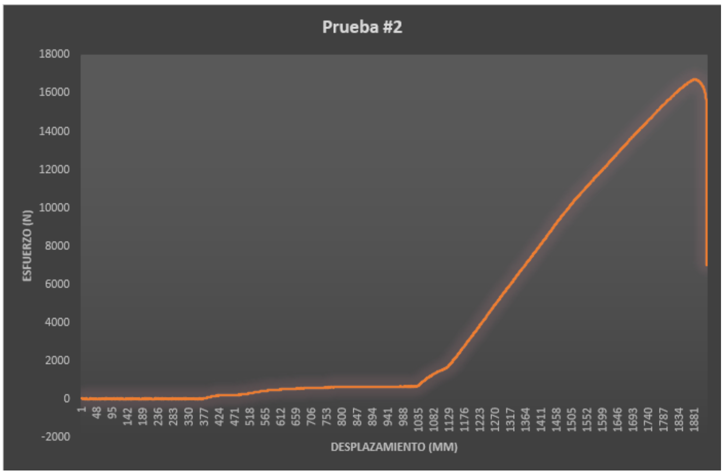


Figure 19.- Stress-strain graph test #2

CONCLUSIONS

This study provides valuable information on the quality of metal-to-metal bonding using a steel-specific epoxy adhesive. The practical implications of these results can guide adhesive selection and optimize the design of similar bonds in industrial applications.

In a nutshell, the design and manufacture of the device for determining the shear force in adhesives in the interpretation of metal-to-metal joints presents a comprehensive approach to evaluate the effectiveness of adhesive bonds in specific applications, contributing to knowledge in the design of structural joints.

The design and manufacture of the device to measure the shear force in the metal-to-metal joint, specifically when bonding a PTR with an aluminum specimen using a type of adhesive, has proven to be an efficient and significant strategy to evaluate the quality and strength of adhesive joints.

The execution of a test using an adhesive, which is epoxy, made it possible to evaluate the adhesion capacity of the adhesives and compare their performance under similar conditions. The choice of a PTR and an aluminum specimen as test materials reflects common practical situations in metal bonding.

The results obtained from shear force tests provide crucial information on the effectiveness of adhesives in terms of strength and durability of metal-to-metal bonds. This is essential in real-world applications, such as manufacturing and construction, where the reliability of adhesive bonds is critical.

The implementation of this device not only contributes to the understanding of the adhesive properties of the materials used, but also opens the door to possible improvements in adhesive formulation or application techniques. These improvements could lead to an increase in the efficiency and durability of adhesive bonds, which is crucial in scenarios where tensile strength and fatigue play a critical role.

In summary, the design and manufacture of this device has provided a valuable platform to evaluate and compare the shear force in metal-to-metal joints through the application of adhesives. The results obtained offer essential information for decision-making in the selection of adhesives and in the design of bonds that meet the resistance standards required in various industrial applications.

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