Strength of Adhesive Bonded Joints: Comparative Strength of Adhesives

Sunday Okerekehe Okpighe

***Abstract*— An experimental investigation of the Comparative Strength of Adhesives is reported. The need for effective and efficient bonding technology to satisfy the niche created due to the IT and Micro-chips revolution is leading the scientists and engineers away from the traditional bonding methods, namely, welding, bolting and riveting among others to the field of Adhesive bonding(due to its efficacy). Consequent on the fore going, an experimental investigation was carried out to determine the impact of the use of different adhesives (as bonding agents) on the strength of an Aluminum –Aluminum plate lap joint. The test specimen was designed and fabricated. Three adhesive types, namely, Araldite Rapid, Bond-It and Pattex Compact were used as bonding agent for the Aluminum specimen. The specimens were subjected to destructive tests in tension on the Mosanto Tensometer machine. The specimen bonded with Bond-It had the highest failure load ahead of the specimens bonded with Araldite Rapid and Pattex Compact respectively in that order. Hence, experimental results conclusively proved that for a specific joint where all the characteristics and parameters of the joint are kept constant, the strength of the joint will be a function of the strength of the adhesive used as bonding agent.**

***Index Terms*— Adhesives, Adhesive Strength, , Adhesive Joint Applications. Bonded Lap Joint**

I. INTRODUCTION

Adhesive (or glue) has been defined as a mixture in a liquid or semi liquid state that adheres or bonds items together and that Adhesives may come from either natural or synthetic sources [1]. According to [2], Adhesives are substances capable of holding materials together by surface attachment. Egyptian carvings dating back 3,300 years depict the gluing of a piece of veneer to what appears to be plank of sycamore. Also [3] defined the word “adhesive” as an adjective or a noun which refers to substances which tend to adhere or stick to other substances; the interaction which develops between adhesives and adherends. On a similar note, [2] posited that papyrus, an early non-woven fabric, has the fibres of reed-like plants bonded together with flour paste. Bitumen, tree pitches and bee wax were used as sealants (protective coating) and adhesives in ancient and medieval times. In the same vein,[2] said that the gold leaf of illuminated manuscript was bonded to paper by egg white, and wooden objects were bonded with glues from fish, horn and cheese. In the 19^{th} century, rubber and pyroxyl in-cements were introduced, but decisive advances in adhesive technology awaited the 20^{th} century, during which natural adhesives have been improved and many synthetic s have come from the laboratories [2]. Adhesives are now essential components of plywood, automobiles, shoes, furniture, cartons, non-woven fabrics, and a host of other products. The raw materials for adhesives are mainly polymeric materials, both naturally and synthetically [4]. According to [2], while the natural products such as hide, glue, starch and dextrin, casein, and natural gums are still important from the standpoint of cost, the synthetics have largely taken over the adhesives industry both as modifiers of natural materials and more importantly , as high-strength, moisture-resistant additives capable of being produced in many readily usable forms. It is the view of [2] that the growth of the aircraft and aerospace industries has had a profound impact on adhesives technology. The demand for high degree of structural strength coupled with resistance to fatigue and severe environmental conditions has led to the development of high performance adhesive materials, counterparts of which have found their way into many industrial and domestic applications [2]. Adhesives may be classified according to use, major chemical constituents, forms, curing process, et cetera [5]. According to [5], the term “structural” has come to mean those used to bond metals to metals, to wood or to rigid plastics, where bond strength is a critical requirement. Three of the most commonly used are the modified epoxies, neoprene-phenolics and vinyl formal-phenolics. In the opinion of [5], Adhesives are finding increasing usage in industry because of certain desirable characteristics, namely:

1) Ability to minimize stress concentrations in bonds
2) Provide smooth, unbroken contours in bonded structures.
3) Ability to join dissimilar materials
4) Ability to attach very thin materials
5) Resistance to fatigue
6) Help to reduce weight of structures
7) Often permit design simplifications
8) Processing: involves low temperatures (room temperatures up to about 176.7^0C, depending upon adhesive); low pressures(contact to several hundred PSI, depending upon adhesive and configuration of structure being fabricated); and short times(minutes to about 24 hours, depending upon adhesive and air temperature).
9) Fabrication costs may be lower than for other joining methods
10) Inherent sealing characteristics
11) Resistance to chemicals (varies with chemical adhesive, and time and temperature of exposure).
12) Shock, sound, vibration dampening
13) Thermal and electrical insulation.

Adhesives for structural applications have been extensively covered in military specifications [5]. Among these, MIL-A-5090 covers metal-to-metal adhesives suitable for use in aircraft, and includes four types based upon service requirements:

Type 1: long-time exposure (192 hours) to temperatures from -55 to 82.2^0C.

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Type 2: long-time exposure to temperatures from -55 to 148.8^{0}C.
Type 3: long-time exposure to temperatures from -55 to 148.8^{0}C and short time exposure to temperatures from148.8^{0}C to 260^{0}C.
Type 4: long-time exposures to temperatures from -55 to 260^{0}C.
In the opinion of [5], only a few adhesives e.g. Epoxy-phenolic blends in tape form, can meet the higher temperature requirements. Specification MIL-A-8623 covers Epoxy-base adhesives suitable for bonding of metals, reinforced plastics, glass and wood for service at temperatures up to 82.2^{0}C. It is the considered view of [5] that while adhesives do provide many desirable attributes, certain limitations should be considered, viz:

1) Possible high initial capital investment for equipment and facilities.
2) Relatively poor stability of currently available adhesive bonds at temperatures above about 204.4^{0}C for extended periods of time.
3) May require mechanical reinforcement where high peel strength is necessary.
4) Working life(during fabrication of bonds) often short, depending on adhesive system, which may necessitate refrigeration and/or special handling procedures.
5) Surface preparation of adherends is critical, especially for structural applications.
6) Very limited non-destructive inspection methods available for bonded assemblies.

According to [5], Adhesives are widely used in virtually every industry – aircraft, rocket and missile, automotive, electrical, appliances, construction, etc. Applications range from temporary attachments such as masking for protection during process operations to highly critical assemblies in aircrafts and missiles. In the words of [5], the greatest usage of adhesive bonding in aircraft is perhaps in honey comb sandwich constructions, e.g. wings, fins, leading edges and other control surfaces, flooring, doors and bulkheads. Bonded sandwiches also find increasing use in such diverse applications as trailers and truck bodies. List of adhesives manufacturers and marketing agents in [6], is as contained in Appendix B. Also other sources of adhesives information include: [7]-[12] among others.. Selecting the proper adhesive for any application must include consideration of the substrate surface characteristics and the application requirements [13]. According to [13], over the years pressure sensitive adhesives (PSA) have become accepted in many applications over liquid adhesives or mechanical fasteners. Pressure sensitive adhesive (PSA) has been defined by [14] as adhesive which forms a bond when pressure is applied to marry the adhesive with the adherends. The incorporation of PSA Technology in a variety of products and applications including printer cartridges, hard disks, computer peripherals, medical devices has been ongoing [13]. According to [13], in preparing for discussion of your applications, considerations must be given to the following questions:

1) What is being bonded? (plastic, foam, and to what?).
2) What are the environmental conditions that the product will see?
3) What is the application?
    a) Example: is it a permanent application, say for the life of the product?
    b) Example: is it a temporary application, say for processing hold?
4) How will the material or part be applied? (by hand or automations?)
5) Will the part need to be die-cut?
6) Estimated annual volumes?

In Nigeria, need to get a particular adhesive for a particular purpose is subjected to some limitations – this is due to the fact that the field of adhesive technology is yet to be fully subjected to critical study. Thus most of the adhesives in use locally belong to the general purpose adhesives (e.g. Evostick used by shoe – makers and carpenters, Partex for floor tiles, etc), with exception of few hard epoxy types like Araldite (Rapid and Standard).

Objectives of Investigation:
To compare the bond strength of the following Adhesives:

a) Araldite Rapid
b) Bond- IT
c) Pattex Compact

using Test Specimen of Fig. 2 (2mm x 15mm cross section) as shown in Appendix B.

II. MATERIALS AND METHODS

A. *MATERIALS*

Mosanto Tensometer (as shown in Fig.1 in Appendix B), Aluminum Test piece (as shown in Fig.2 in Appendix B), Adhesives: Araldite(Rapid), Bond-It and Pattex.

B. *METHODS*

Preparation of Specimens
Aluminum pieces were first cut to approximate grip width from the parent Aluminum sheet using the hand shear machine. These strips were then cut to the exact lengths required. The exact dimensions of the test piece was marked on one of these strips(using scribers, steel rule, tri-square, etc).The 8mm hole for the machine grip was drilled in with the aid of the rotary drill. There after, this test piece was used to mark similar drill point of 8mm diameter hole. After the completion of the drilling process, 5 test pieces of the same length and dimensions for a particular test were bolted together and reduced to an approximate gauge length using the Sacia Shaping machine. Those test pieces were then smoothened using files and emery cloth. Problems encountered in the process include that of using the hand shearing machine to cut thick Aluminum plates (2mm thickness) due to the small size of the machine and the fact that the machine was not fixed to the ground as at then. Filing such a large number of test pieces to exact size was not quite an easy job. A lot of precautions were taken in preparing the test pieces:

a) It was ensured that the test pieces were as straight as possible after the cutting process with the hand shear machine(using the anvil to straighten test pieces).
b) It was ensured that there was on eccentricity in the test pieces- this was done by marking the centre line on the test pieces before boring in the grip holes.

c) Precision of the gauge length dimensions being an important factor in obtaining the desired aim of the experiments- it was ensured that the exact gauge width was not attained by the shaping machine, and files were used to put finishing touches to the test pieces in order to get high precision of the width dimensions.
d) By use of the hand shear, presence of residual stresses in the test pieces cannot be entirely ruled out, neither by use of the shaping machine could repeated stresses (thus strain) be ruled out of the test pieces. Use of flat files on specimen gives rise to repeated stresses too.

In the process thus it was ensured that steps which could increase either residual or repeated stresses were reduced, viz:

a) By cutting through short distances with the hand shear.
b) Using medium speed range of the Sacia Shaping machine and ensuring that little cut was taken at a time.
c) Using the hand file to do gradual reduction of surfaces of test piece.

Adhesive Bonding Process

The surfaces to be bonded were properly smoothened using hand files and then given a slight degree of roughness using emery cloth. The surfaces were then cleaned with cloth wetted with soap-water until there was no sign of grease or dirt. The surfaces were then finally cleaned with Acetone and allowed to dry. Equal amounts of fluid were squeezed from the Araldite tubes on to the cover plate and mixture stirred with the spatula continuously for about 20 seconds (as stipulated by the manufacturers). A thin layer of Araldite was then applied to the two surfaces to be joined, the surfaces were then held in place together for about 10 to 15 minutes (by which time the Araldite (Rapid) got strong enough to stick both pieces together). The bonded piece was then left for about 20 minutes to grow strong, after which the excess Araldite was scrapped off with the aid of a knife. Precautions taken include:

a) Ensuring that there was no eccentricity in each of the test piece joints.
b) That the fluid from both tubes of Araldite were equal (within limits of inspection error), as variation in the proportionality of the mixture can result in weak bonds.
c) Since Araldite is dangerous to the eyes, care was taken to keep mixture away from the eyes and skin (washing hands with soap-solution in hot water each time after bonding process.
d) Care was taken to ensure that the Acetone in use was kept away from any source of fire since Acetone is highly inflammable.

Determination of Adhesive Film Thickness in Bond for the Bonded Joints

The thickness of the Adherends were measured with a Micrometer Screw Gauge before the bonding process. The joint thickness was measured after the bonding process and the difference in these two values give the adhesive film thickness in the bonded joint.

METHOD

The gauge length was marked off on the specimen, the cross-sectional dimensions taken. Laminate lengths, laminate widths and araldite(adhesive) film thickness were noted. The spring beam and the scale fitted on the Tensometer were noted. Also the gear ratio (magnification factor) being used for the drum drive was noted. A new chart paper was installed on the chart drum. The chart paper was zeroed at the start of the test. The specimen was the mounted on the machine by advancing the right hand jaws with the quick-acting handle. The worm gear was disengaged for this operation after which it was re- engaged once the specimen has been mounted. Alignment and tautness in the mounting was checked for. While a friend turned the handle to move the jaws (using the slow- acting handle), I did the recording of the load/elongation on the paper by following the mercury with the point and perforating the paper at regular intervals.

Precautions Taken In Course Of Experiment

a) Punctures were made more frequently near the yield point to determine the exact yield point.
b) It was ensured that the handle was turned at constant speed, as the reverse should have affected the load/elongation curve.
c) It was ensured that the specimen did not slip in the jaws.

III. RESULTS AND DISCUSSIONS

RESULTS

A. ARALDITE(RAPID)

Table 1(First Test)

LOAD (Kg)	FORCE (N)	STRESS x $10^6 Nm^{-2}$	ELONGATION x 10^{-4}m	STRAIN x 10^{-2}
0	0	0	0	0
100	981	2.62	13.89	1.4
200	1962	5.23	27.78	2.85
235	2305.35	6.15	32.74	3.36

Gauge length =97.5mm
Overall length = 187mm
Adhesive layer thickness – 0.1mm
Failure stress = 6.15 x$10^6 Nm^{-2}$

Table 2(Second Test)

LOAD (Kg)	FORCE (N)	STRESS x $10^6 Nm^{-2}$	ELONGATION x 10^{-4}m	STRAIN x 10^{-2}
0	0	0	0	0
100	981	2.62	10.91	1.1
200	1962	5.23	19.84	2.03
265	2599.65	6.93	26.79	2.75

Adhesive layer thickness = 0.1mm
Failure load = 6.93 x $10^6 Nm^{-2}$

Table 3(Third Test)

LOAD (Kg)	FORCE (N)	STRESS x $10^6 Nm^{-2}$	ELONGATION x 10^{-4}m	STRAIN x 10^{-2}
0	0	0	0	0
100	981	2.62	10.91	1.1
200	1962	5.23	21.83	2.24

292.5	2869.4	7.65	30.75	3.15

Adhesive layer thickness =0.1mm
Failure stress = 7.65 x $10^6 Nm^{-2}$.

Table 4(Fourth Test)

LOAD (Kg)	FORCE (N)	STRESS x $10^6 Nm^{-2}$	ELONGATION x 10^{-4}m	STRAIN x 10^{-2}
0	0	0	0	0
100	981	2.62	5.3	0.54
200	1962	5.23	11.25	1.15
300	2943	7.85	17.21	1.77
345	3384.5	9.03	20.18	2.07

Adhesive layer thickness = 0.25mm
Failure stress = 9.03 x $106 Nm^{-2}$
Mean failure stress = [(6.15 + 6.93 + 7.65 + 9.03) x $10^6 Nm^{-2}$]/4
= 7.44 x$10^6 Nm^{-2}$

B. BOND-IT

Table 5 (First Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
100	6.290
200	12.58
230	15.22

Table 6 (Second Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
55	2.98
105	5.95
160	9.92

Table 7(Third Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
100	5.96
200	12.56
272.5	17.21

Table 8(Fourth Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
100	7.94
150	11.91

Table 9(Fifth Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
100	5.95
200	12.90
275	17.86

Table 10(Sixth Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
200	15.88
300	23.13
395	30.76

Neglecting values of Tables 6and 8,
Mean failure load = (230Kg +272.5Kg + 275Kg + 395Kg)/4 = 293.13Kg
Hence , Ultimate Shear Stress (τ) =(293.13Kg x 9.81 ms^{-2})/[(15 x 10^{-3}m) x (25 x 10^{-3}m)] = 7.67 x 106 Nm^{-2}
Mean Elongation = [(15.22 + 17.21+ 17.86 +30.76) x 10^{-4}m]/4 = 20.26 x 10^{-4}m
Percentage Elongation = (Mean Elongation/Original Length) x 100%
= [(20.26 x 10^{-4}m)/(97.5 x 10^{-3}m)] x 100% = 2.08%

Tensile Stress (σ) = (293.13Kg x 9.81ms-2)/[(2 x 10-3m) x (15 x 10-3m)]
= 95.85 x $10^6 Nm^{-2}$

C. PATTEX COMPACT

Table 11 (First Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
0.78*	3.97
0.78	23.81

Table 12 (Second Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
2.19*	4.62
2.5	10.58
2.5	24.47

Table 13 (Third Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
1.88*	14.55
1.88	53.58

Table 14 (Fourth Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
1.25*	11.91

Table 15 (Fifth Test)

LOAD(Kg)	ELONGATION x 10^{-4}m
0	0
1.72*	10.91
1.72	37.7
0.938	55.56

*= Elastic Limit Load.
Neglecting values of Tables 11 and 14,
Mean Failure Load = (2.50Kg + 1.88Kg + 1.72Kg)/3 = 2.03Kg.
Mean Ultimate Shear Stress (τ) = (2.03Kg x 9.81ms^{-2})/[(15 x10^{-3}m) x (25 x 10^{-3}m)]
= 0.053 x $10^6 Nm^{-2}$
Mean Elongation = [(10.58 + 14.55 + 10.91) x 10^{-4}m]/3 = 12.01 x 10^{-4}m

Percentage Elongation = $[(12.01 \times 10^{-4}m)/(97.5 \times 10^{-3}m)] \times 100\% = 1.23\%$

Tensile Stress = $(\sigma) = (2.03Kg \times 9.81ms^{-2})/[(2 \times 10^{-3}m) \times (15 \times 10^{-3}m)] = 0.66 \times 10^{6}Nm^{-2}$

Table 16(SUMMARY)

ADHESIVE TYPE	FAILURE LOAD(Kg)	ULTIMATE SHEAR STRESS x $10^{6}Nm^{-2}$	% ELONGATION
ARALDITE (RAPID)	284.38	7.44	2.83
BOND-IT	293.13	7.67	2.08
PATTEX COMPACT	2.03	0.053	1.23

DISCUSSIONS

Data in Tables1 – 4, represent the experimental results obtained in testing specimen using Araldite Rapid adhesive. The mean failure load obtained is 284.38Kg with a corresponding ultimate shear stress of 7.44 $x10^{6}Nm^{-2}$ and percentage elongation of 2.83.

These values are displayed in Table 16(the Summary Table)

In similar vein, data in Tables 5-10, represent the experimental results obtained in testing specimen using Bond-It adhesive. The mean failure load obtained is 293.13Kg with a corresponding ultimate shear stress of 7.67 x $10^{6}Nm^{-2}$ and percentage elongation of 2.08. These values are displayed in Table 16(the Summary Table).

Also, the data in Tables 11-15, represent the experimental results obtained in testing specimen using Pattex Compact adhesive. The mean failure load obtained is 2.03Kg with a corresponding ultimate shear stress of 0.053 x $10^{6}Nm^{-2}$ and percentage elongation of 1.23. These values are displayed in Table 16(the Summary Table).

From the results in Table 16, it is obvious that the strength of a bonded joint depends on the strength of the Adhesive used. Bond-It has the highest failure load and hence the strongest of the three, while Pattex Compact is the weakest of the three adhesives.

IV. CONCLUSION

Results from investigation of the strength of adhesives reveal that Bond-It has the highest strength ahead of Araldite Rapid and Pattex Compact. From this experimental result therefore, a conclusion can be drawn that when all characteristics and parameters of a joint are kept constant, the strength of the joint will be a function of the strength of adhesive used as bonding agent.

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REFERENCES

[1] Wikipedia(2010), Adhesives- Wikipedia, the Free Encyclopedia. En.wikipedia.org/wiki/Adhesives.

[2] Benton, William.,(1943-1973), Encyclopedia Britannica. Vol.1. Pp. 88-90.

[3] Cassavabiz(2010), Cassava Adhesives. www.cassavabiz.org/postharvest/glue01.htm

[4] Rowland a. Glen(1998), Adhesives in the Journal of Adhesives and Adhesion. CHEM NZ. I998, No. 71. Pp.17-27. nzic.org.nz/ChemProcesses/polymers/10H.pdf

[5] Reinhold (1967), The Encyclopedia of Engineering Materials and Processes. Reinhold Publishing Corporation, New York. Pp 15-17.

[6] Shields, J.,(1970), Adhesives Handbook. Butterworths, London

[7] Solutions (2010), Industrial Adhesives –Structural, Non-Structural, Bonding Tapes---. www.Solutions.3m.com/wps/portal/3M/en_US/3M--/Adhesives/

[8] Adhesives.org (2010), Adhesives.org, Home Page. www.adhesives.org.

[9] Permabond (2010), Adhesives, Epoxy, Cyanoacrylate, Sealants and Acrylics. www.permabond.com

[10] Holdtite (2007), Welcome to Holdtite – Performance Adhesives. 25 September 2007. www.Holdtite.com.

[11] Selleys(2010), Building and Construction Adhesives. www.selleys.com.au/Building--Adhesives/default.aspx

[12] Adhesiveresearch(2010), Adhesive Research Manufactures Custom Pressure Sensitive Adhesives. www.adhesiveresearch.com/

[13] .Fralock(2010), Conductive Adhesives. www.fralock.com

.[14] Wikipedia(2010)[1], Pressure – Sensitive Adhesive – Wikipedia, the Free Encyclopedia. En.wikipedia.org/wiki/pressure-sensitive-adhesive

APPENDIX A - ADHESIVE MANUFACTURERS AND AGENTS.

MANUFACTURERS	LOCAL AGENTS	TRADE NAME OR DESIGNATION	BASIC TYPE	NO.OF COMPONENTS	METHOD OF APPLICATION	PROCESSING: CURING CYCLE	PROCESSING: BONDING PRESSURE	ADHERENDS
CIBA-GEIGY LTD. BASEL, SWITZERLAND	UTC (NIG.), BENIN, NIGERIA	ARALDITE (RAPID)	EPOXY	2	SPATULA	4H AT 30^{0}C. 8H AT 23^{0}C. 16H AT 10^{0}C. 25H AT 5^{0}C	CONTACT	METALS, PLASTICS, LEATHER, GLASS ETC.
		ARALDITE STANDARD	EPOXY	2	SPATULA		CONTACT	METALS, PLASTICS, LEATHER, GLASS, ETC.
HOLD PRODUCTS LTD., LIOYDS HOUSE, WILMSLOW, CHESHIRE, USA.	UTC(NIG.), BENIN, NIGERIA	BOND-IT	CYANOACRYLATE	1	SPRAY DROPS		CONTACT	METALS, RUBBER, MOST REGULAR PLASTICS, CERAMICS
HENKEL INTERNATIONAL, GMBH DUSSELDORF, WEST GERMANY	MOST LOCAL SPARE PARTS AGENTS	PATTEX COMPACT		1	SPATULA OR SPREADER		HIGH PRESSURE	PLASTIC LAMINATE, WOODEN EDGES, RIGID PVC, WOOD,METAL, LEATHER, FELT, FABRIC, RUBBER.

SOURCES OF FURTHER INFORMATION ON ADHESIVES

RESEARCH ASSOCIATIONS AND OTHER ORGANIZATIONS

1) ADHESIVE TAPES MANUFACTURERS' ASSOCIATION, C/O SMITH AND NEPHEW, WELWYN GARDEN CITY, HERTS.
2) ADHESIVES MANUFACTURERS' ASSOCIATION, 21 TOTHILL STREET, LONDON S.W.1.
3) ATOMIC WEAPONS RESEARCH ESTABLISHMENT (AWRE), ALDEMASTON, BERKS, DAVID DEVERALL, DIV. CHEM. TECH., NEWBURY 1800.
4) *ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH, HANTS, MR. L.N. PHILLIPS – MAT. DEPT. 0252-24461.

APPENDIX B

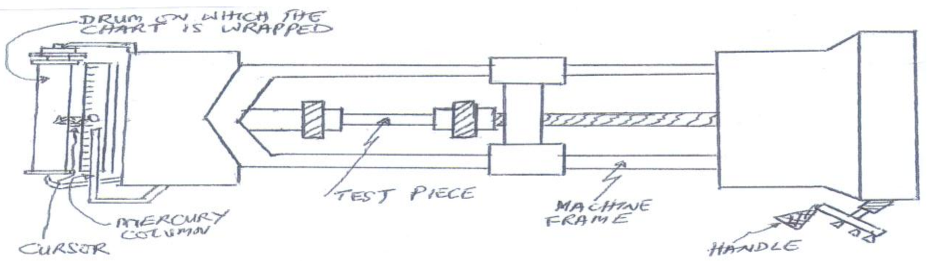

FIG. 1 – MOSANTO TENSOMETER

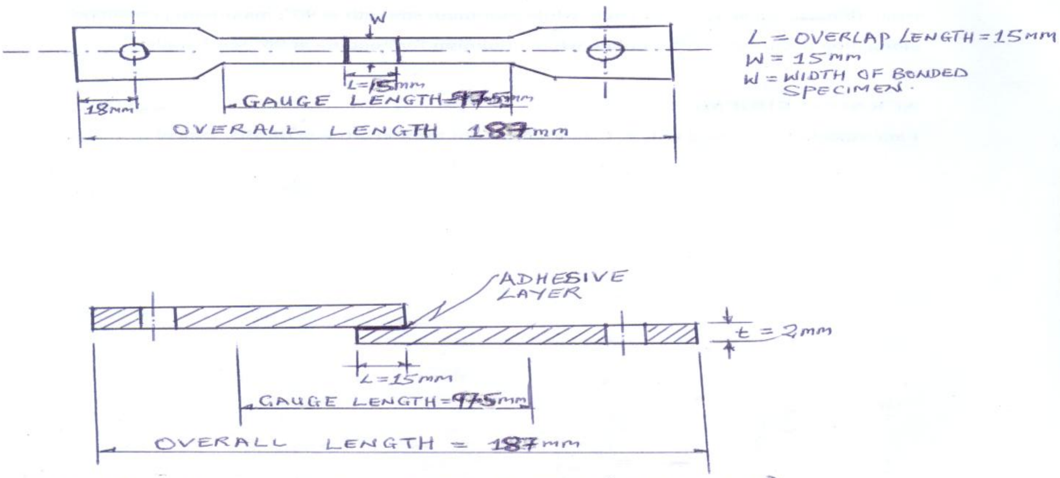

FIG. 2 – ALUMINUM TEST PIECE (SPECIMEN)