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Comparative Analysis of Mechanical Properties of Structural Adhesive

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***Abstract:** In every industry joint are usually bonded or joined either by welding or with the help of some type of adhesive and reliability of these joints is very important for the quality of product. So different types of analytical and experimental as well as theoretical studies are performed to find and check the mechanical attributes of the given adhesive. Depending upon the different studies there are two prime groups of research. First one is the bulk sample testing and second one is the joint sample testing.*

The mechanical properties of the used adhesives are measured by performing different strength tests like tensile, compression and shear testing.

In this dissertation a study is performed on the mechanical properties of the DP410 adhesive. First of all in different types of joints this structural adhesive is used and then different tests are performed for checking the strength of this structural adhesive. Digital Image Correlation method will be used to find the mechanical properties of structural adhesive. With the help of this method different stain value are verified where this adhesive loss strength and bonding power can be easily known. By this research adhesive strength can be used to find given adhesive is better for which particular joint.

I. INTRODUCTION

A. Development

The requirement for the development of quite lightweight structures and also the industry prefers to use of lightweight materials in industrial fields and all of this phenomenon have now moved the world to wide use of adhesive joints in last decade. There are various applications of these adhesive joints that contain bonding of metallic and other body panels for automotive and flight vehicle structures where quite lightweight and very much high fatigue strength is a fundamental requirement. Adhesive used should be convenient and reliable in case of static and dynamic behavior of adhesive joints [1].

Different adhesive are used worldwide to make bonding in between joints and different research have been conducted worldwide to find the mechanical properties of these adhesives. Depending upon the research that was conducted across the globe these bonding techniques can be classified into two collections.

First collection aim to perform different bulk specimen tests that were carried out directly from the bulk adhesive and second collection targets to perform test on joining two plates with the given adhesive under the given conditions in which adhesive has to be used. The mechanical attributes of the used adhesive is known by performing tensile, compression and shear tests of these samples. [2-3]

Usually the failure of adhesively bonded joints happens when there is high stress occurred and this is the maximum stress which is of researcher interest.

In contrast to the use of fasteners in mechanical joints it is found that if adhesive bonding is used then it will provide a continuous as well as more connecting area that shows the lower stress concentration.

Manufacturer of lightweight and high performance vehicles usually use fastening and welding to join the dissimilar metals and it is found that these techniques are generally unsuitable for creating bond between dissimilar materials. Many technique have been used worldwide to find the strength of these adhesive material when is used to join the two metals. Techniques like Digital Image Correlation, TAST etc. are used these days to find the strength of adhesives.

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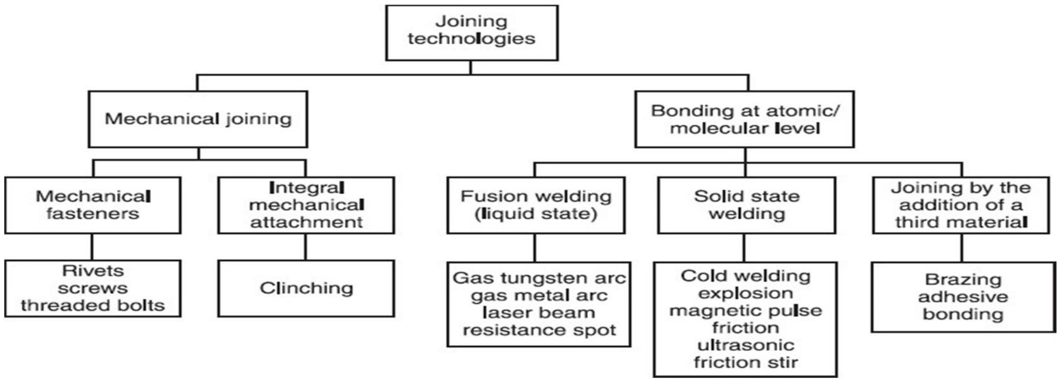

Figure 1.1: Classification structure of joining bonding technologies [32]

B. Adhesive Bonding

It is a process where two or more mechanical parts or composites are joined by the use of adhesive material and it could be accomplished by the solidification or by the hardening processes. The surfaces of the bonding material which were joined are heated by some process. So thistechnique behaves similar to brazing and soldering but still it is a chemical process. To create inner bond either evaporation or vaporization of a solvent or cooling of a liquid may occur.

There are two types of chemically reactive adhesive hardening systems.

1) Cold hardening
2) Heat hardening systems

Among the various metals present aluminium is the most ideal metal which could be used for adhesive bonding. This is due to the reason that it has a good surface energy with the help of that it helps the organic adhesives to easily wet its bonding surfaces. Further the long lasting mechanical behavior of the adhesively bonding joints depends on the nature of the adhesives and the environment. The selection of a particular adhesive is dependent upon the how much strength is required for the bonded joints and which type of stress is available on the joint.

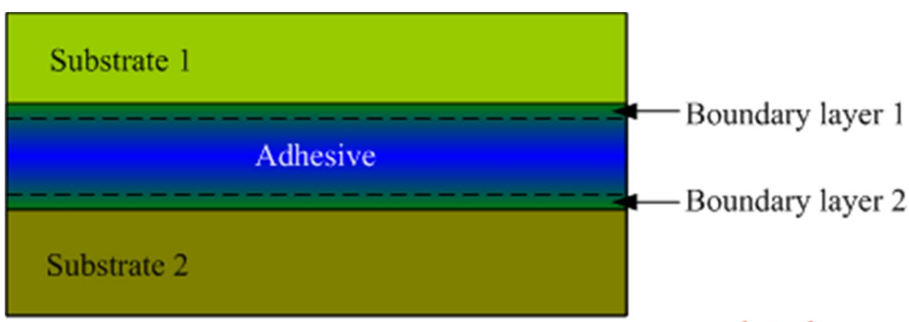

Figure 1.2: Structure of adhesive joint [40]

Usually epoxy types of adhesive are used for jointing aluminium metals that can be cured at room temperature either by slow or fast processing. If elevated temperatures are used than these adhesives show high performance and resistance towards the moisture. The basic requirement for these types of epoxy adhesives are cleaning and preparation of the surface of the metal.

Adhesive bonding is based on the principle of adhesion. Actually adhesion is a mixture of various physicochemical processes which usually occurs at the joint or the touching interface of the two materials when those materials are very close to each other that results in some attractive pull amid two metals or materials. While the adhesion strength is a force that is required to separate two different adhered joints along the interface of the metals. [14]

At present Anerobic acrylic adhesives are used for bonding aluminium alloys. These adhesives usually dissolve thin films of oil into the adhesive layer of metal and it does not affect the strength of the bonded joint. The most effective use of adhesive bonding in any type of manufacturing process depends on the conditions of a particular process, design of joint and as well as on the selection of adhesive.

C. Stages Of Adhesive Bonding

1) *Assembly and Joint Design:* This is the initial stage for the adhesive bonding process. This stage is required for the proper design which provides minimal peel as well as low cleavage stresses. If not used then it could increase the tension, compression as well as shear stress.
2) *Adhesive Selection:* This stage is required for the proper selection of a adhesive which is further relied on the various conditions like which type of substrate material is used, what is the service temperature and the environment, what is the requirements to the bonding strength as well as requirement of flexibility and durability.
3) *Surface Preparation:* This stage is highly recommended as in this state the surface of the substrate is thoroughly cleaned from any time of noises like dirt and oils, and after then it is abraded. The benefit of cleaning and roughened surfaces is that it provide fine wetting of the adhesive, which can further give us strong adhesion. Further surface preparation is done with some surface characterization methods. It includes
   a) *Visual Inspection:* It is performed to check whether pre treatment was carried out homogeneously on the entire surface of the material.
   b) *Surface Resistance Testing:* It is used to check contamination which may be present after performing pre-treatment in case of abrasion as well as blasting.
   c) *Water Break Test:* It is a qualitative step in which water is poured on the surface of the metals so that if after performing blasting or abrasion some containment is there on the surface then it could be washed away.
4) *Spreading of Adhesive:* In this stage selected adhesive is uniformly spread over the substrate surface. This operation is globally carried out by both automatically as well as manually with the help of various instruments.
5) *Assembly Stage:* In this stage assembly of various mechanical or other specimen which have to be joined are assembled.
6) *Clamping Stage:* In this particular stage the various mechanical parts are fixture with at various controlled pressure so that joint do not become loose.
7) *Curing:* In this process to create a strong bonding joint the adhesive molecules are cross linked. For a particular type of adhesive the curing process may vary.

D. Failure Of Adhesive Bonding

At present there are three ways which are responsible for the failure of adhesive bonding.

1) *Structural Failure:* It is an internal failure which is present in the region near to the joint ofa substrate material.
2) *Adhesive Failure:* It is a typical type of interfacial failure that would happen when there is separation of one of the substrate from the adhesive layer.
3) *Cohesive Failure:* It is one of the failures of the internal layer of the adhesive layer.

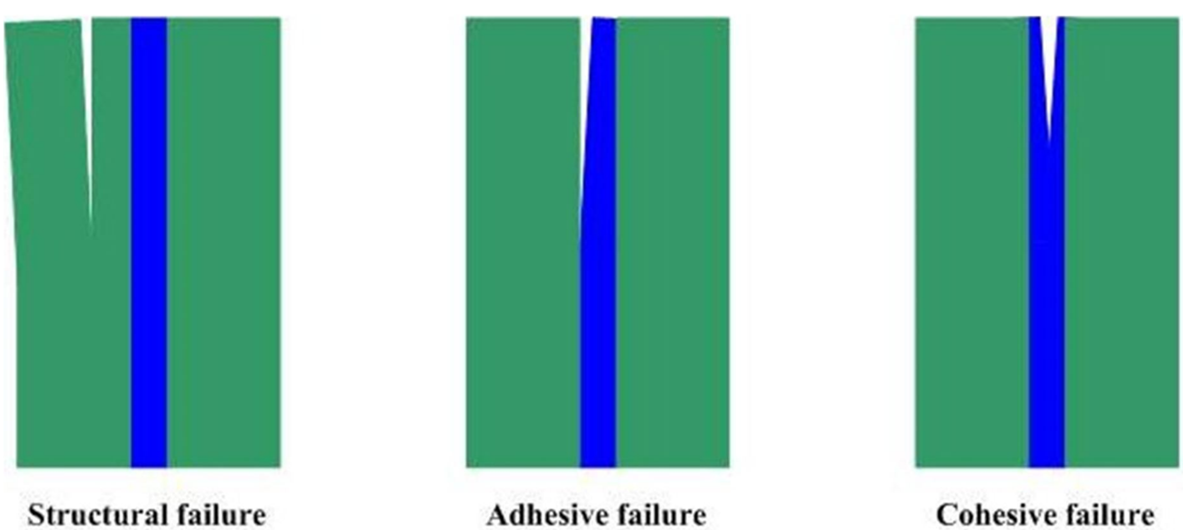

Figure 1.3: Failure mechanism of adhesive bonding [40]

E. General Defects In Adhesive Bonding

There are various types of defects that can be raised in the adhesive bonding process. In the given figure some detail is present that shows the adhesive bonding amid tow different composites.

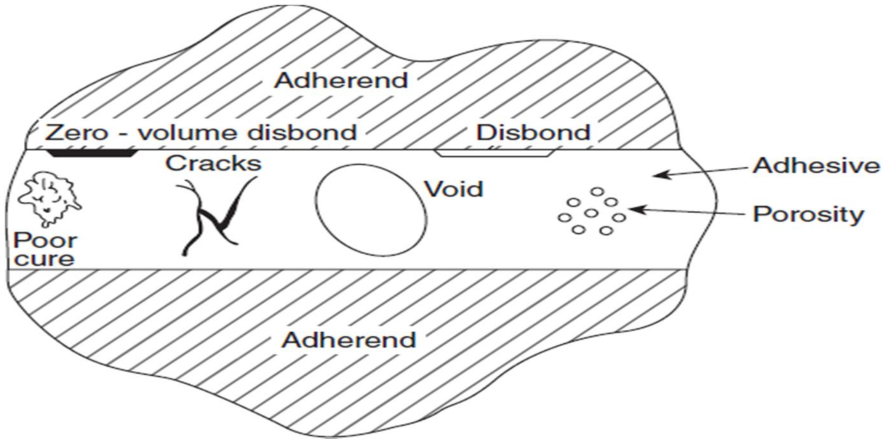

Figure 1.4: Defects in bonded joints [30] Due to the present of defects following conditions may occur

1) *Aadherend/Substrate:* There may be occurrence of cracks, dents, scratches, holes
2) *Interface:* On the interface there may be disbonds, zero-volume disbonds or weak/kissing bonds may occur
3) *Adhesive Layer:* There may be porosity, voids, cracks, poor cure may occur

F. Epoxy Adhesive

There are various types of adhesives and out of which epoxy adhesives are used wildely for various purposes.

1) *Advantages*

a) This adherent is not affected by heat
b) It provide a stable uniform distribution of stress
c) It is helpful to join quite large surfaces
d) It is used for joining various distinct materials
e) It is fully stable in joining very thin adherents
f) It is fully Gas proof as well as liquid-tight
g) It shows zero crevice corrosion
h) It shows zero contact corrosion
i) There is no requirement of precise fits of the adherent surfaces
j) It shows better damping properties in contrast to other adhesives
k) It shows quite good dynamic strength
l) It provides no distortion
m) Provides good strength to weight ratio
n) It provides smooth boundaries

2) *Disadvantages*

a) It shows very limited stability against the heat
b) If used for long time it may vary the attributes of the bond-line
c) In almost all scenarios there is requirement of both cleaning as well as surface preparation of the adherents
d) At most of time specific clamping devices are need to fix the bonding joint
e) The quality testing like non destructive testing is only feasible to a certain extent
f) Inspection of joint is quite difficult
g) It is a rigid process and control is required
h) Special training may be required
i) Long cures may be required

3) *Applications*
a) It is used for bonding of metal to various non-metals especially plastics is the major application of adhesive bonding.
b) It is utilized as an alternative to riveting for aircraft structures.
c) It is broadly used in fastening process of stiffeners to the aircraft skin and as well as used in the assembling honeycomb structures in aircraft
d) It is used largely in the fabrication of aircraft internal structures and benefit of that is it gives the smooth surface for supersonic planes.
e) It is useful in automobile industry to attach brake lining to shoes, automatic transmission bands, and stiffeners
f) It has also various applications in the fabrication of railway coaches, boats, refrigerators, storage tanks, and microwave reflectors for radar as well as in the space communications.

4) *Digital Image Correlation (DIC):* Basically Digital Image Correlation is abbreviated as DIC and is most advanced non contacting image relied deformation measurement technique. The benefit of this technique is that it is capable of analyzing various materials under various loading circumstances like thermal, mechanical or other environmental loading. This DIC technique has various applications in many areas of engineering like mechanical, material science and biomedical engineering. [20-23]. When we talk about material testing then this method involves the tracking of movements of patterns either originated naturally or movements of applied surface patterns generated by applied load to any sample material in the process of performing mechanical testing. The full three dimensional surface measurement is also possible with the help of stereoscopic multi-camera arrangements.

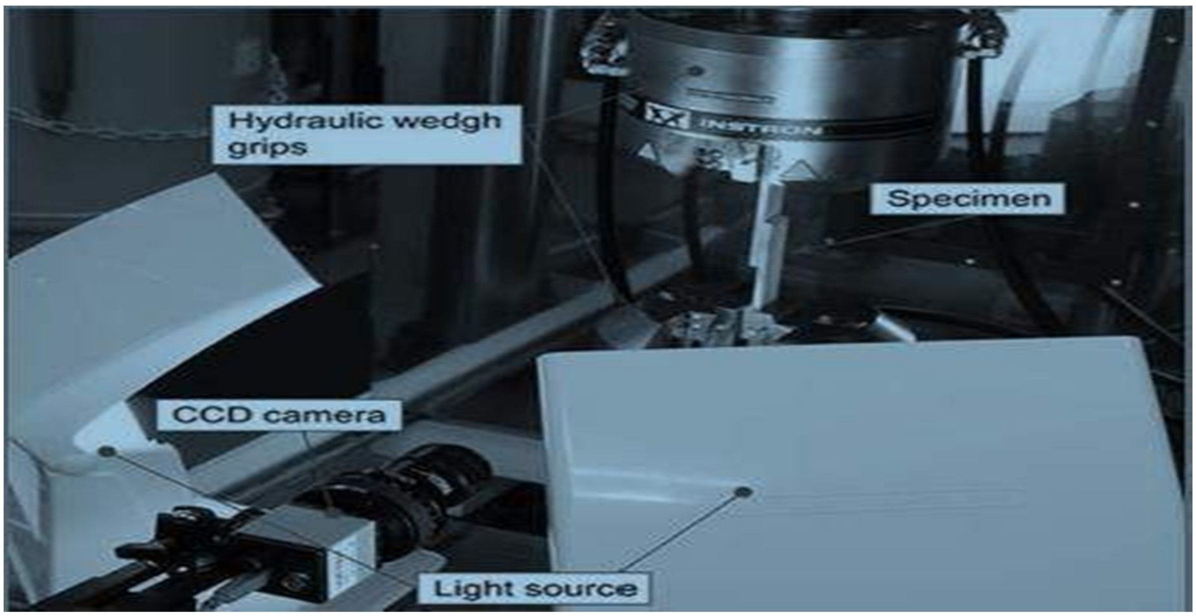

Figure 1.5: Experimental setup of DIC [15]

In the DIC process measurement the different criteria are used in the experiment. These criteria's are not limited to these like Cross Correlation Criterion (CCC), the Sum of Absolute Differences Criterion (SAD) and also the Squared Sum Differences Criterion (SSD) are utilized in the determination of sample displacement via digital images recorded. Now the there might be some variations in the pixel costs of the digitized images of the digital images which are recorded at various time slots of the experiments. [15]
As a result the similarity gap amid the reference and deformed digital images decreases. And as a result the overall accuracy of the DIC is also lowered. Now to compensate the given loss of pixel costs various correlation techniques like Zero-Normalized Cross-Correlation Criterion (ZNCC) and the Zero-Normalized Squared Sum of Differences Criterion (ZNSSD) have been developed.
Now these recorded digital images are partitioned in the analysis of this DIC process into small regions which are subsets and into sub-regions with the identical gray level distribution in the reference and the deformed digital images are judged utilizing one of the already mentioned correlation algorithms. The displacement of the sample is found out in the analysis of DIC process by utilizing shape functions as well as mapping functions. It should be remembered that the adequacy of the degree of shape function utilized for the given analysis changes depending onthe sample movement.

II. LITERATURE SURVEY

E. C. Kavdir et al. [3] in 2019 presented an investigation on the mechanical properties of the DP410 structural adhesive. The experiment had two stages. First stage was aimed to find the mechanical attributes of the adhesive and in the second stage mechanical behavior of the adhesively joined single lap joint with the same adhesive. Authors used Digital Image Correlation method to study the behavior. Authors used bulk and joint form samples were derived from liquid adhesive and different loads like tensile and shear were applied. Experiment showed that the DIC method showed prominent results for finding the mechanical properties of adhesive. Authors found that DIC could be an alternative in comparison to extensometer technique. Authors also proposed that accuracy of the method could also be increased if the 3 dimensional DIC analysis with high resolution camera was used.

S. Guangyong et al. [8] in 2018 performed a study by investigating the effect of the thickness of the adhesive with adherend type of single lap joints on the fracture characteristics. Authors used the digital image correlation method to study the deformation and the process of fracture due to stress distribution as well as strain evolution along the given bondline in the adherend. Both the fractured process and the deformation of the joints were monitored by the charge couple device camera during the performance of tensile stress. Here authors used four other metals to create adhesive joints which were Q235 steel, 5182 aluminium alloy, woven carbon fiber reinforced plastic (CFRP) as the adherends and the epoxy adhesive which would treated as an adhesive agent.From the outcomes of the experiments authors showed that with the rise in thickness of adherend the bond length also increased.

S. Kawasaki et al. [15] in 2017 performed a deep analysis on the mechanical bonding joints so that the stress concentration could be lowered. After studying various papers authors suggested that if mixed adhesive joints (MAJs) which had brittle as well as ductile adhesive could help in overcoming the stress concentration at the bonding joints. Authors created joints by using rigid adhesive in the center part of the overlapped area and flexible type of adhesive in the ending part of the overlapped area and their stress distribution was analysed. So authors used single lap joints were force under the tensile load to find out the stress distributions in the adhesive as well as the adherend layer of the given joints.

A. B. Morais [16] in 2017 evaluated the shear behavior of the structural adhesive for the given bonding joints with using a beam prototype. Authors performed three bending test points. Authors knew that in all types of mechanical tests the strain measurements had deep impact. Many methods like strain gauge, extensometer and optical strain measurement techniques were utilized to perform these evaluations. Authors found that the DIC method could be broadly used in strain measurements due to its large benefits.

J. V. Blitterswyk et al. [20] in 2016 used TAST technique to find the mechanical properties of adhesive ASTM D5656. Authors utilized and developed method so that it could be used as an alternative to KGR-1 extensometer which was generally used to find the shear deformation of the adhesive during use of TAST test method. So authors used two dimensional DIC methods. The results obtained from this method were found to be very reliable in comparison to result obtained from the KGR-1. The authors found that DIC method is less time consuming and is cheap in comparison to other used method.

S. S. Shrestha et al. [22] in 2015 performed the experiments using DIC technique to analyses the bonding joints. Authors applied silicon pollutant with various rates on the bond line of adhesively bonded joint which was formed with carbon fiber reinforced composite (CFRP). Authors used aluminum materials for investigation in this research. The results were found satisfactory.

K. S. Wei et al. [31] in 2013 performed a study regarding the DIC process. The main aim of this research was to design and create a 2D deformation calculation process. Authors used two separate materials and performed tensile test and the perform investigation by capturing the high resolution images of this process. Authors used the MATLAB software to analyze the recorded image results from two methods and results were found reliable.

T. Sadowski et al. [33] in 2010 performed various researches in steel adhesive mechanical double lap joints (DLJ) which were bonded with rivets and could be easily applied to various stems of engineering like aerospace, mechanical and civil. Authors performed three types of investigations by using three types of joints. First joint was created by only rivets. Second joint was created using adhesives and third joint was created using adhesive and rivets. The testing of the experimental study was performed with the help of 3D digital image correlation system known as ARAMIS so that distortions lengths could be monitored along the testing phase to break down phase. In this study authors used Hysol 9514 adhesive for the bonding.Authors found that the adhesive type of joints performed better in comparison to rivets.

M. H. F. Cunha et al. [34] in 2009 performed a detailed investigation to find the effect of various mechanical elements like strain as well as stress distributions and displacements of the mechanical bonding joints. Authors performed both the experimental as well as numerical analysis of mechanical double lap joints which were reinforced with the help of rivets. In the experimental study authors calculated the displacement measurements with the help of digital image correlation technique.

While the finite element analysis method was utilized in the numerical section of the research. Also authors found that the energy absorption rate of rivets is thirty five percent more in contrast to rivets. Further authors found that the with the sudden variation in the thickness of the cross section region at the overlapped ends there was concentration of axial tension.

M. D. Banea et al. [35] in 2009 performed investigation with the two different flexible adhesives namely Sikaflex 552 as well as AS1805 RTV and performed various joint tests with adhesives. These adhesives were fall in the category of polyurethane and other one was a high temperature thixotropic adhesive sealant which became silicon rubber at room temperature and was also termed as room temperature vulcanizing (RTV). In the presented investigation authors generated adherend shear test (TAST) specimens for finding the shear mechanical attributes of the given adhesives. Also the single lap joints were produced for finding the performance behavior of adhesives.Further authors performed various shear test strengths of the given adhesives at various temperatures and various overlap lengths as well as various thickness values of adhesive. Authors found that the shear strength was varied due to the above factors.

Cognard et al. [36] in 2008 performed TAST and modified Arcan technique utilized to find the shear mechanical attributes of structural adhesives by performing test samples in binding form. Various numerical experiments showed that adhesive showed non linear behavior where rotational as well as plastic deformations appeared at the loose ends of the bonded joint and damaged started at that part. Further authors found that due to this situation error happened and it became hard to get properties by TAST technique. So authors used modified Arcan technique and quite homogeneous stress distribution could be produced in the used bonding area and this method showed good results.

B. Pan et al. [37] in 2008 had utilized the functionality of Digital Image Correlation (DIC) for finding the relative displacements of bending joints on the sample surfaces under investigation. It was done with the help of original underformed digital image with the target regions of the deformed digital image. Authors investigated the outcome of displacements on the region of material surface that could affect the validity of the DIC measurement method. Further authors used the Sum of Squared Differences (SSD) on the two dimensional theoretical prototype.

It means measurement criteria of DIC machine is based on this SSD intensity gradient.Authors also showed that by using the high performance hardware or by the help of frame averaging method the image noise could also be decreased further. S. Temiz et al. [38] in 2006 carried out a study by using finite element analysis which was used further for stress analysis. Authors used two types of adhesive.

First one was in the stiff form while the second one was the flexible form. The names of the adhesive used were 2214 regular and other was SBT 9244 and these were applied on the AA2024-T3. These both adhesive were selected so that both should had various varying mechanical attributes. These adhesives were applied in the mechanical joints which were double strapped. Further authors studied the bending moment of joints by applying stiff type of adhesive in the center part of the overlap region of joint and flexible type of adhesive was applied at the extreme edges of the joint.

Aydin et al. [39] in 2004 performed an experiment in which single lap joint (SLJ) mechanical properties were numerically analyzed. Authors performed four points pending experiments under bending moment where single lap joints are joined by two types of adhesives namely FM 73 as well as SBT 9244.

Authors performed various investigations on varying the overlap lengths. Also scanning electron microscope (SEM) was used for examining the lap joints fracture surfaces. Authors performed stress analysis with the finite element method where the non linearity property both the adhesive and the adherend (AA2024-T3) were studied. After conducting various experiments authors found that the with the rise in the overall length the strength and joining power of adhesive named SBT 9244 was considerably increased while in case of adhesive FM 73 there was no increase in joining power with increase in overlap length and notable thing was that the FM 73 adhesive was used three times in the bulk form as compared to the SBT. Author also figure out that the large strains were also sustained by the adhesive layer in case of SBT joint and also showed that peel stress concentrations which were the main factor of a joint failure could be handled better in case SBT adhesive.

III. PROBLEM FORMULATION

In every industry joint are usually bonded or joined either by welding or with the help of some type of adhesive and reliability of these joints is very important for the quality of product. So different types of analytical and experimental as well as theoretical studies are performed to find and check the mechanical attributes of the given adhesive. Depending upon the different studies there are two prime groups of research. First one is the bulk sample testing and second one is the joint sample testing. The mechanical properties of the used adhesives are measured by performing different strength tests like tensile, compression and shear testing.

So there is need of research to be performed to get the mechanical properties of the DP410 adhesive. First of all in different types of joints this structural adhesive is used and then different tests are performed for checking the strength of this structural adhesive. Digital Image Correlation method will be used to find the mechanical properties of structural adhesive. The work was carried on Digital Image Correlation System, 230V, 60 Hz and DP410 Adhesive at Trikuta Aluminium Industries, Udhampur, (J&K).

IV. RESEARCH GAP AND OBJECTIVES

A. Research GAP

After having a comprehensive literature survey, the various research gaps that were identified which are described here :

1) At what point DP410 structural adhesive cohesive property fails.
2) To find how much stress can be applied on the bonded material.
3) Depending on the type of test performed on the bonded material how the adhesive strength of bonded joint behaves.

B. Research Objectives

This research work will be focused to achieve the following objectives

1) To study and implement the different stress values on the adhesive bonded joint.
2) To find the maximum strength of adhesive along different test performance.

V. RESEARCH METHODOLOGY

A. Research Methodology

In this proposed research the AISI 1020 steel is adhered with the DP410 which is used as an adhesive and this all setup is used to find out the mechanical properties of this adhesive under various load conditions. The DP410 adhesive provides high strength for joining metals, plastic and other materials. Further various properties of AISI steel 1020 like chemical composition, mechanical and thermal properties of steel are also discussed. Moreover digital image correction technique is discussed which is used to find out the outcomes of the experiment.

There are some steps which have to be performed to complete the research work

1) Take different metals to be bonded
2) Join with the adhesive.
3) Perform the different tests with DIC process.
4) Check the parametric values of these bonded joints.
5) Check the accuracy of result obtained from the process.

B. AISI 1020 Steel Properties

AISI 1020 steel is normally utilized in role of hardened condition and vastly utilized in case of simple structural applications like in case of cold headed bolts. The application of AISI 1020 steel is not limited to utilization for manufacturing of axles, basic engineering of machinery parts and its components. It is also used in shafts and camshafts, gudgon pins, ratchets, light duty gears as well as in spindles.

AISI 1020 shows quite low hardenability values and is also a small value of Brinell hardness of tensile carbon steel with a range of 119 to 235, and also has a good tensile strength in the range of 410 to 790 MPa. Further this steel has shown high machinability, as well as high strength and high ductility and also quite high weldability properties. It is basically utilized in turned as well as polished also in a cold drawn condition.

It has very low value of carbon in its core and shows good behavior as a resistant for both induction hardening and flame hardening. As the steel does not have alloying elements so it does not favor of nitriding. But the steel is favorable for carburization process for the purpose of obtaining case hardness with good value of Rc65 for small regions. This value decreases with the increase in section size. But the core power of steel will remain identical.

Results show that carbon nitriding can also be performed in case of AISI 1020 steel with some suitable conditions and shows significant benefits in comparison to standard carburizing. So both nitriding as well as carburizing both can be performed under some suitable conditions, *1) Mechanical Properties of AISI 1020*

Table 5.1: Mechanical properties of AISI 1020

Density (×1000 kg/m3)	7.7-8.03
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	190-210
Tensile Strength (Mpa)	394.7
Yield Strength (Mpa)	294.8
Elongation (%)	36.5
Reduction in Area (%)	66.0
Hardness (HB)	111
Impact Strength (J)	123.4

2) Thermal Properties of AISI 1020

Table 5.2: Thermal properties of AISI 1020

Thermal Expansion (10^{-6}/ºC)	14.8

3) Chemical Composition of AISI 1020

Table 5.3: Chemical composition of AISI 1020

Element	Content
Carbon, C	0.17 - 0.230 %
Iron, Fe	99.08 - 99.53 %
Manganese, Mn	0.30 - 0.60 %
Phosphorous, P	≤ 0.040 %
Sulfur, S	≤ 0.050 %

4) DP410

DP410 epoxy adhesive has a property of low flow and is a two-part structural adhesive. It is designed for use where toughness, high strength and rapid cure are intended.

DP410 offers the following features:

a) Very rapid cure at room temperature
b) Cure rate may be accelerated by the application of mild heat
c) Convenient 2:1 mix ratio by volume

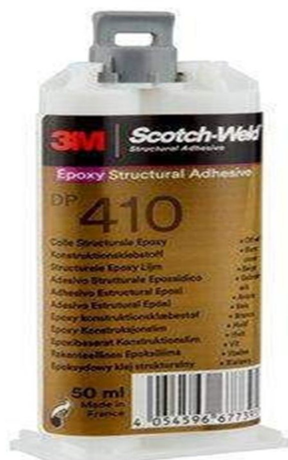

Figure 5.1: DP410 epoxy adhesive

Table 5.4: DP410 epoxy adhesives properties

	Base	Hardener
Base	**Toughened Epoxy**	**Modified Amines**
Color	**Off-White**	**Off-White**
Consistency	**Low sagging paste**	**Low sagging paste**
Specific Gravity	**1.14**	**1.07**

VI. RESULTS AND CONCLUSION

A. Results

In this study, six single lap joints were produced by bonding AISI 1020 with DP410 liquid adhesive. All single lap joints specimens were used in the tensile tests. The AISI 1020 plate was cut according to the dimensions as shown in Figure 6.1 using numerically controlled machines which was then subject to surface preparation processes before the bonding process.

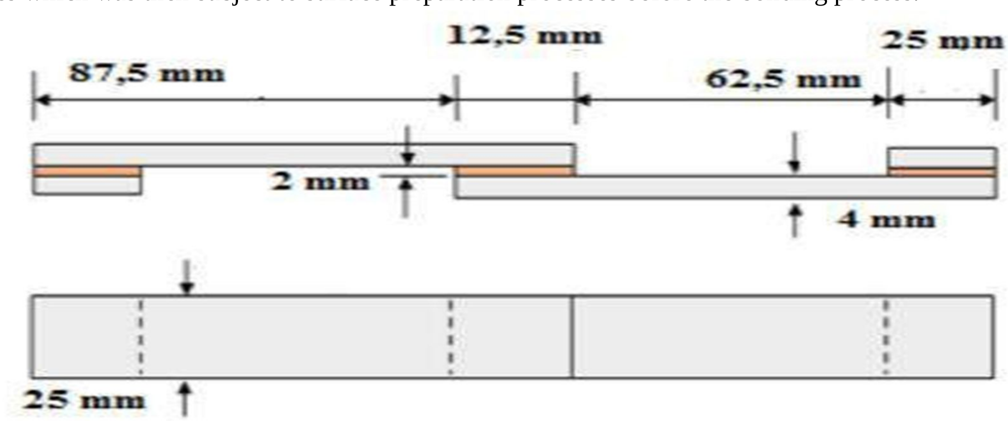

Figure 6.1: Dimensions of the material used for preparing single lap joint

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Single lap joints specimens were tested in the present study using a computer controlled 100 kN capacity 5982 Model Instron universal test device at 21 degree Celsius and 28% humidity. Specimen tests were performed at a deformation speed of 1 mm/min. The digital images of tensile specimens mounted on the testing machine are shown below in various cases.

In addition, the digital images were captured with Instron AV 2 machine video extensometer so that various deformations could be easily examined in the adhesive layer and the adherend via DIC technique, as a result of which strains were obtained. Actually the installed software in the DIC partitioned the digital images into various sub-regions called subset and tries to find the displacement of each and every sub-region utilizing the shape functions that optimize the correlation coefficient.

Following figures show the various lap joints which were used for performing tensile stress using DIC analysis.

Figure 6.2: Lap joint number 1

Figure 6.3: Lap joint number 2

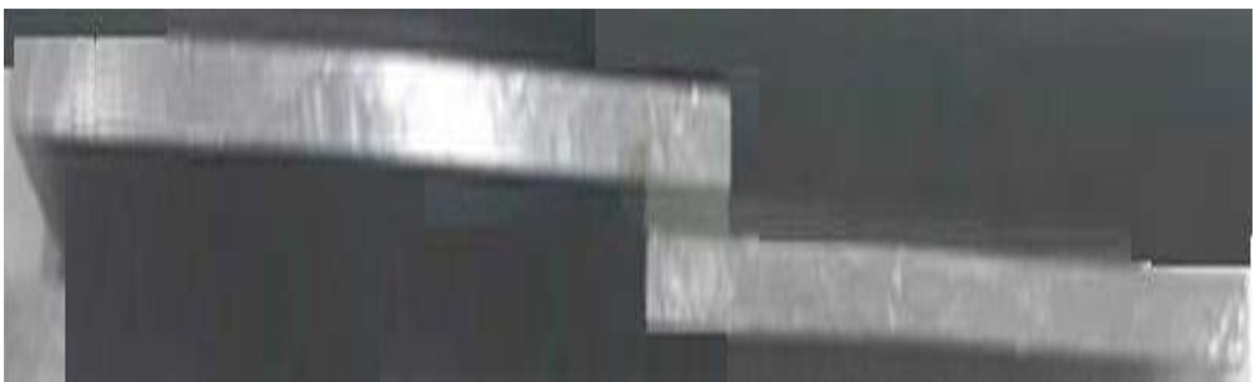

Figure 6.4: Lap joint number 3

Figure 6.2, 6.3 and 6.4 are showing the various single lap joints which will be used for further processing.

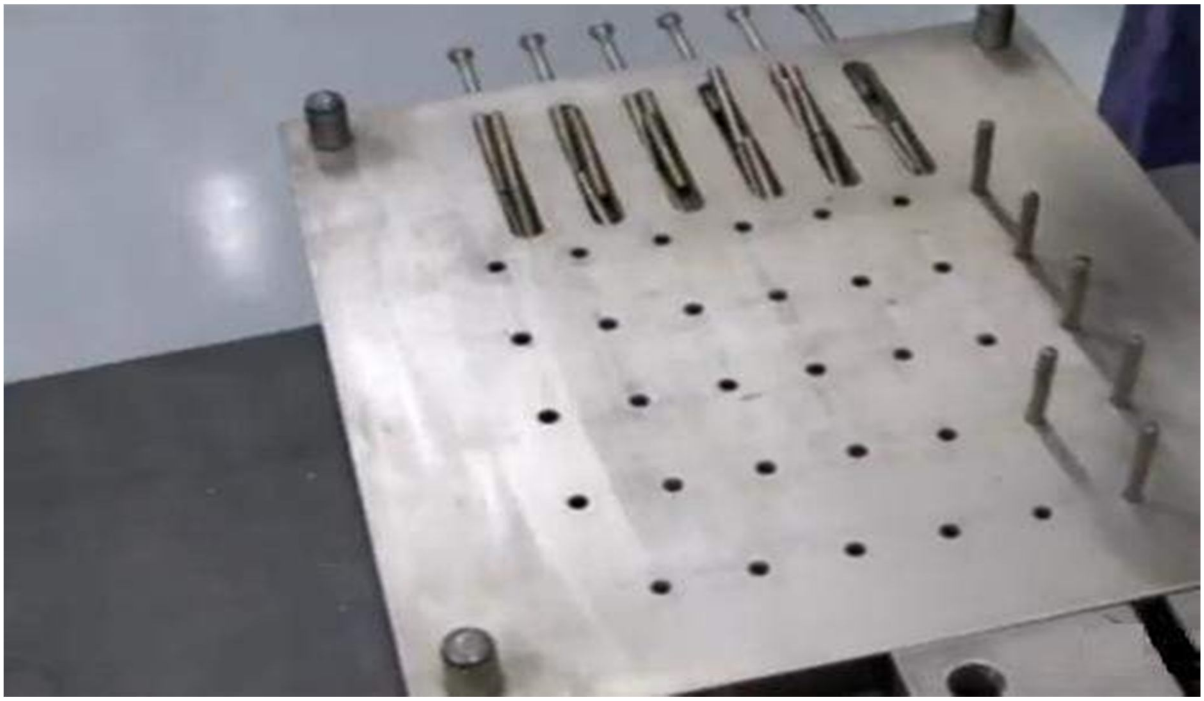

Figure 6.5: Single lap joint preparation setup

Figure 6.5 showing the setup for creating single lap joint for further processing.

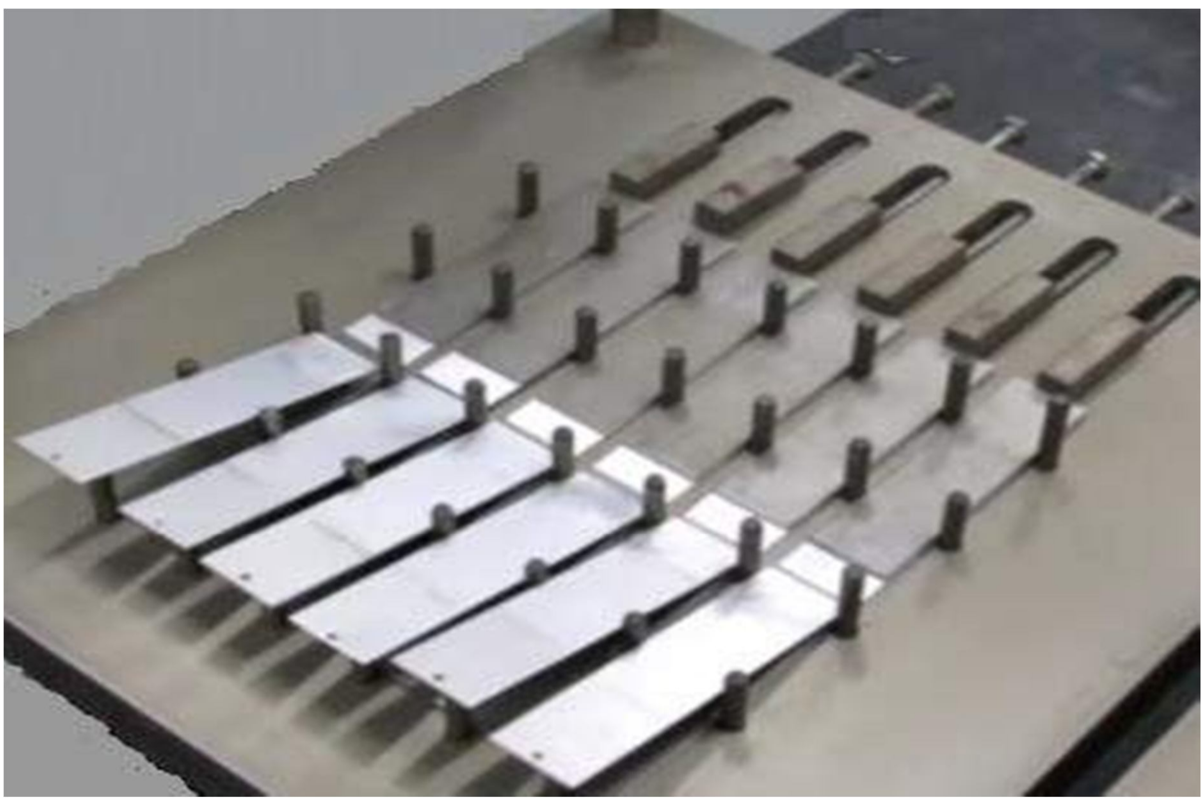

Figure 6.6: All six plates are setup for single lap joint preparation

Figure 6.6 is showing all the six plate set which will be used for further processing of lap joints.

Figure 6.7: Adhesive is used for single lap joint preparation Figure 6.7 showing lap joints with the given adhesive.

Figure 6.8: Heating machine for curing the single lap joint preparation

Figure 6.8 is showing the curing machine which is used for hardening the adhesive so that a firm bonding joint is formed.

Figure 6.9: Removing unwanted material from single lap joint preparation

Figure 6.9 is showing the process of removing the unwanted material from bonded joint.

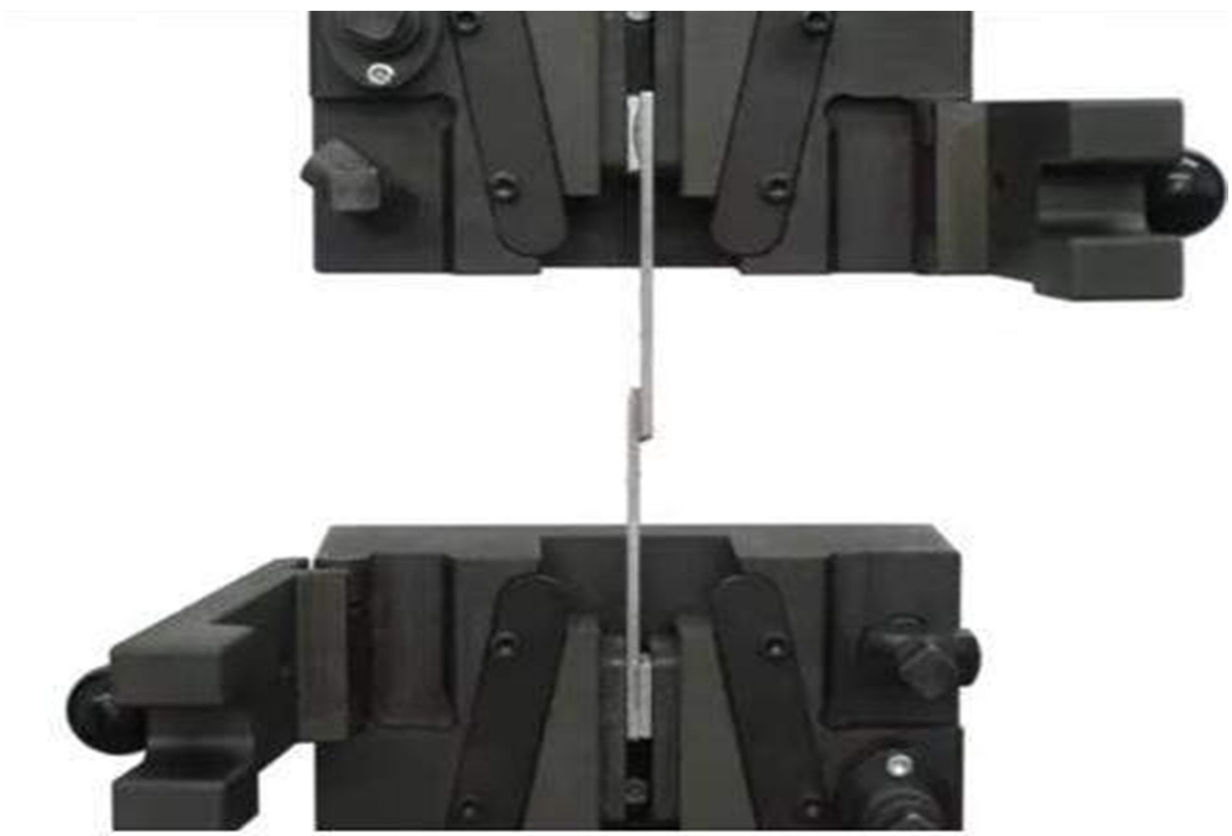

Figure 6.10: Setup for performing tensile stress for single lap joint Figure 6.10 is showing the setup for the tensile stress process.

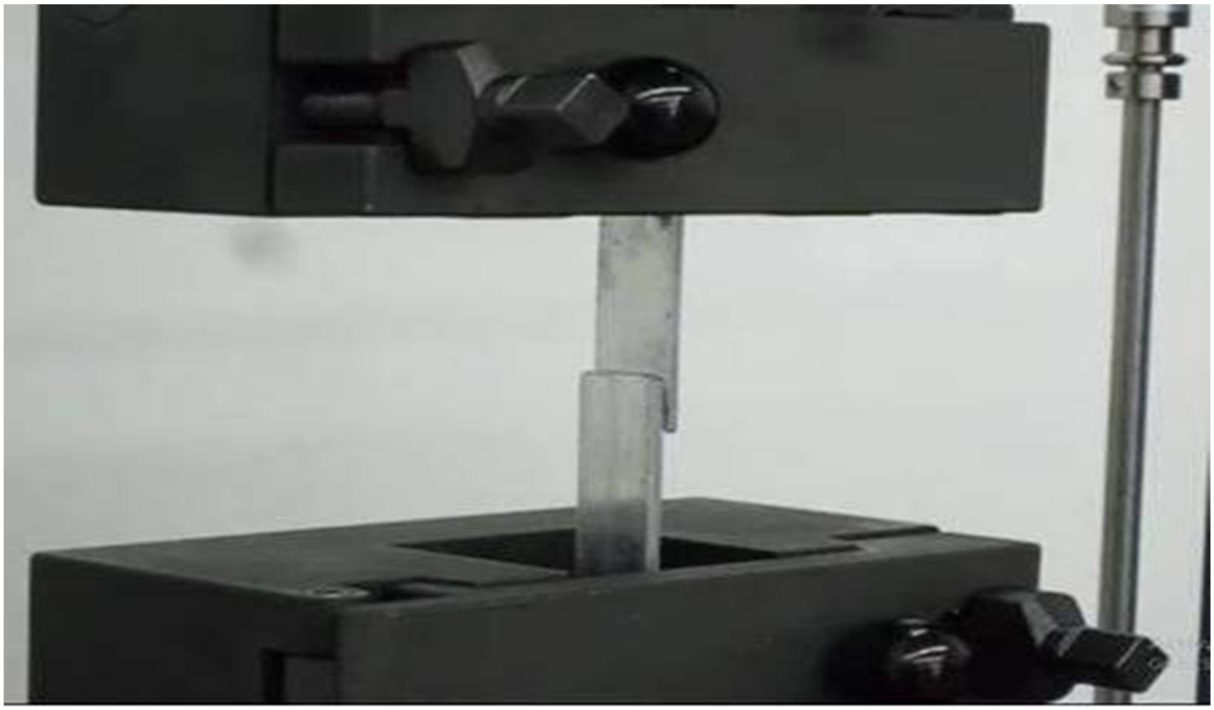

Figure 6.11: Load is applied in the tensile stress In figure 6.11 tensile stress is applied on the single lap joint.

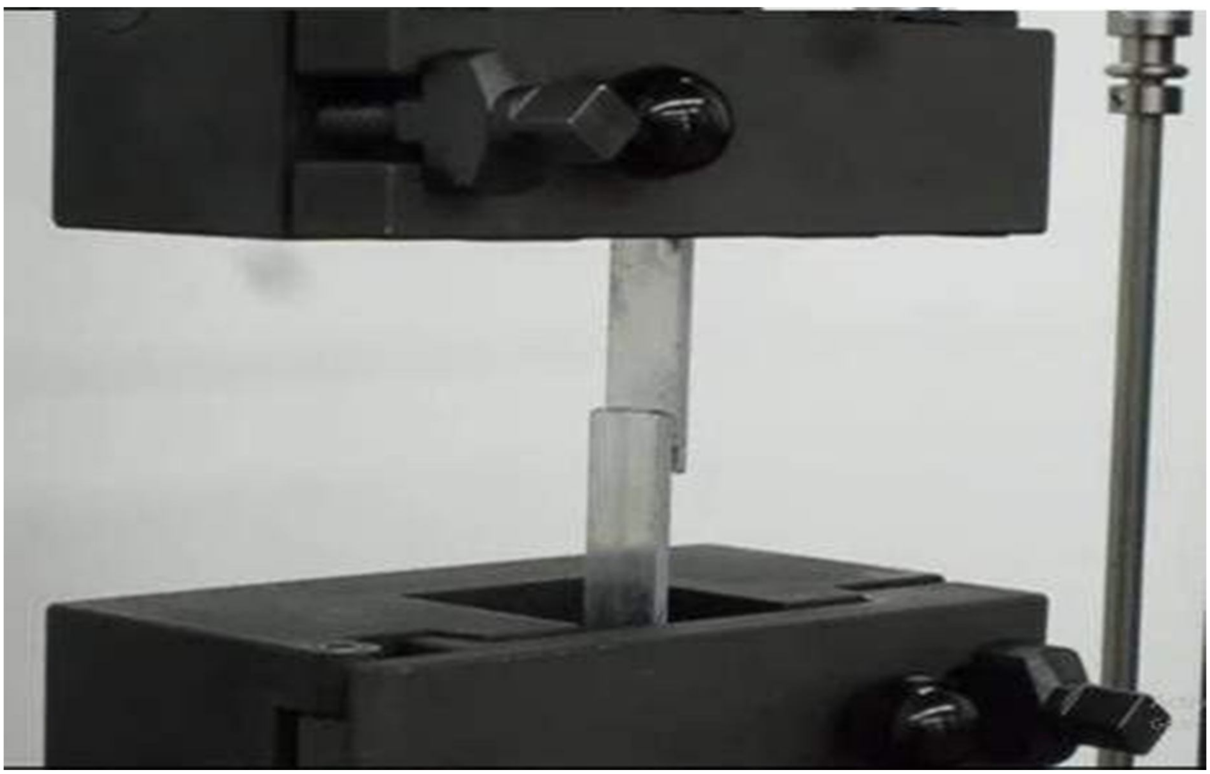

Figure 6.12: Failure occurred after applying tensile stress on single lap joint Figure 6.12 is showing the failure of the joint when tensile stress is applied.

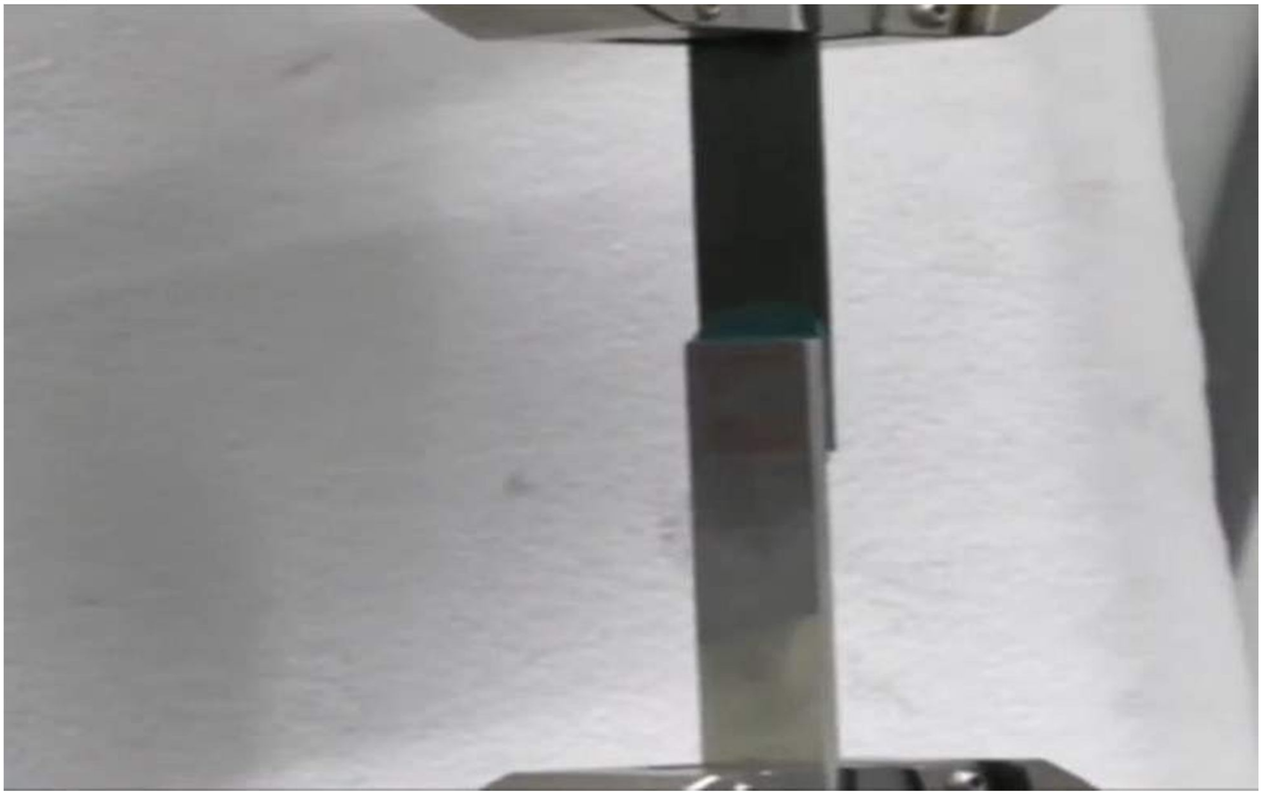

Figure 6.13: Second example of applying tensile stress on another single lap joint Figure 6.13 is showing the tensile stress is applied on the single lap joint.

Figure 6.14: Failure starts after applying tensile stress on second single lap joint Figure 6.14 is showing the tensile stress is applied on the lap joint and the breaking process started to appear.

Figure 6.15: Failure of the single lap joint preparation after applying tensile stress Figure 6.15 is showing the final failure of the joint.

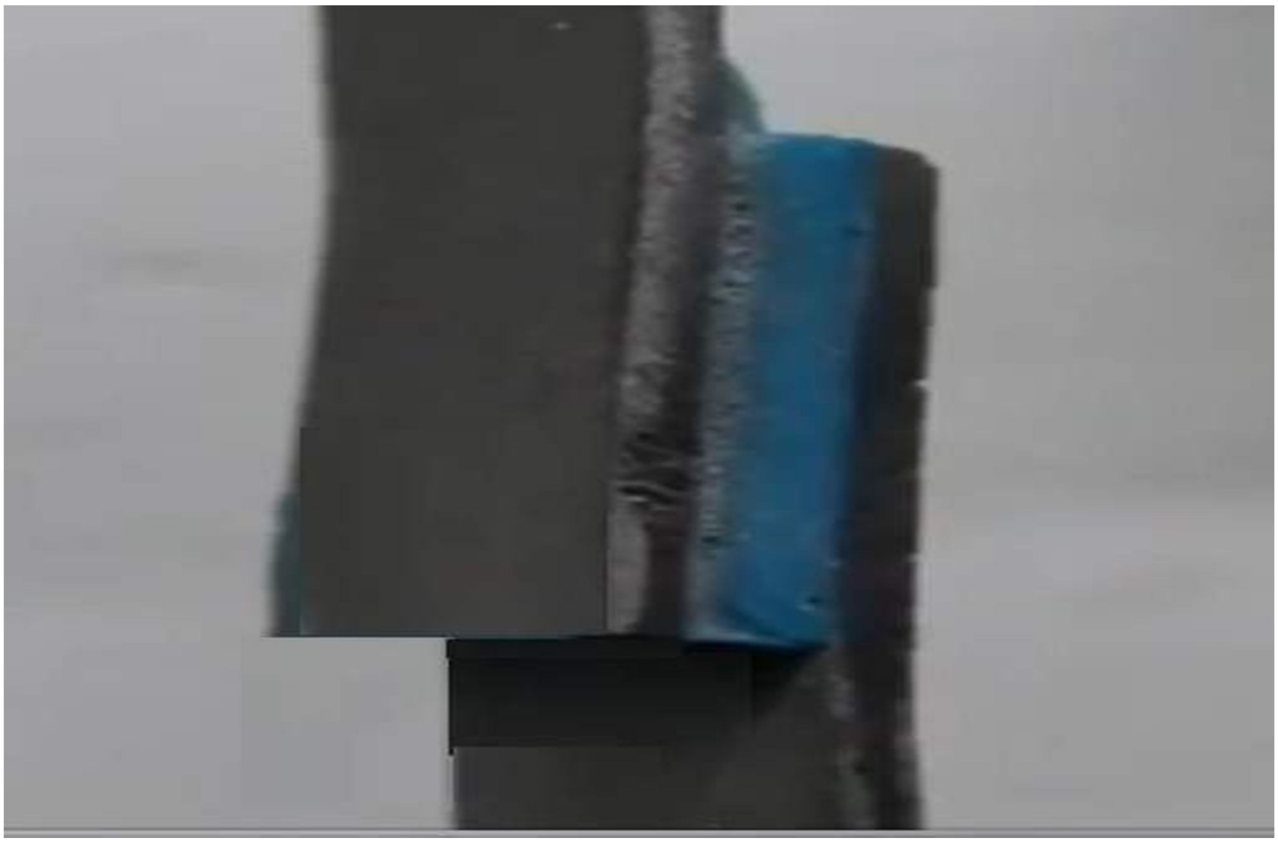

Figure 6.16: Close look up by DIC images of single lap joint Figure 6.16 is showing the DIC image captured by setup for tensile step

Figure 6.17: Bending of the alloy is captured by the DIC

Figure 6.17 is showing that after applying tensile stress the joint is started to bend from joint point.

Figure 6.18: Failure of the bonding images captured by DIC

Figure 6.18 is showing the intermediate image captured by DIC setup which is showing breakage of the bonding.

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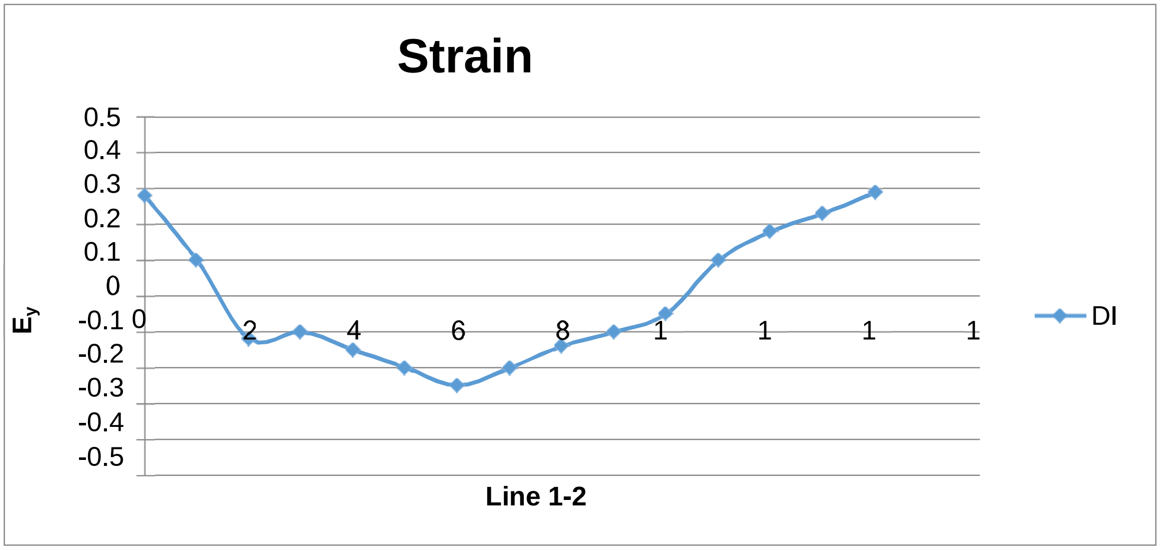

Figure 6.19: Normal strain distribution curve for DIC analysis

Figure 6.19 is showing the normal strain distribution curve for DIC analysis. The graph is plotted between elongation across y-axis.

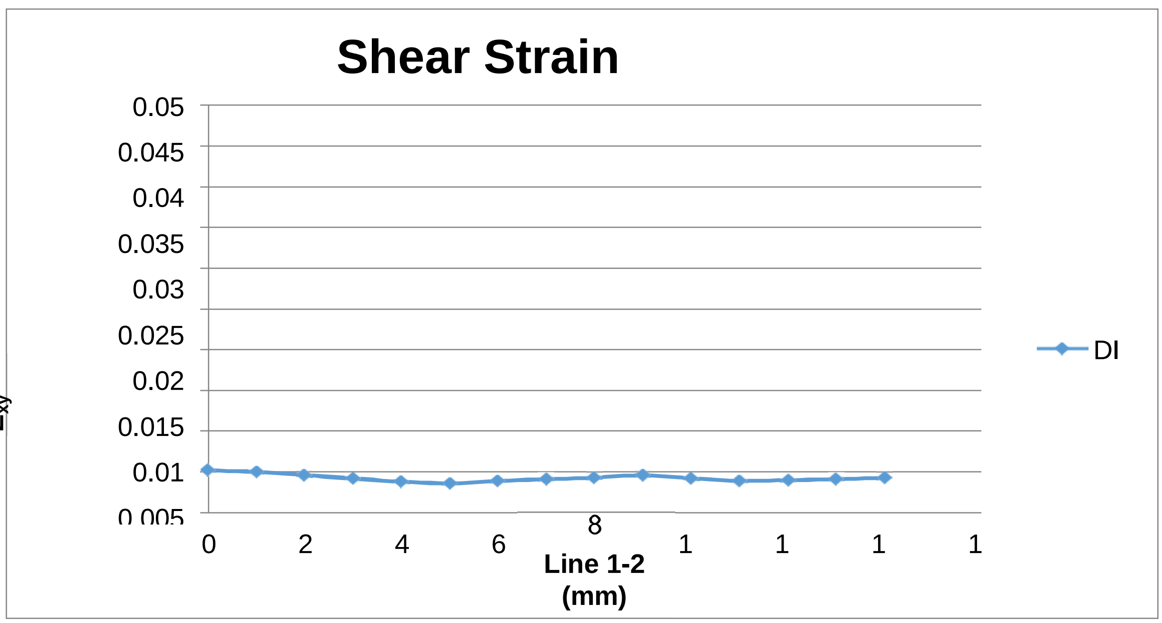

Figure 6.20: Shear strain distribution doe DIC analysis Figure 6.20 is showing the shear strain relationship where elongation is on x-y axis.

B. Conclusion

The normal and shear strain distributions obtained via the DIC technique is shown in Figure 6.19 and figure 6.20 which were compared at a load of 3000 N along the line 1–2 that represents the center line of the given adhesive layer. The normal strain distributions in the thickness direction was shown in Figure 6.19 and from the investigation it was found that the strain distributions obtained from DIC method was compatible as per the standard. In Figure 6.20, that showed the stress strain distribution however it was observed that there is no good agreement in the shear strain distributions as the graph has showed quite low value. It was due to the reason that the DIC technique used was based on two dimensional analysis. For getting more accurate results other techniques of DIC analysis could be used.

C. Future Work

In the future work 3D digital image correlation setup could be used for getting further accurate results. Also high precision cameras could be used to get the good digital images so that fine analysis could be generated from that. Also the DIC analysis could be compared with other method like finite element analysis.

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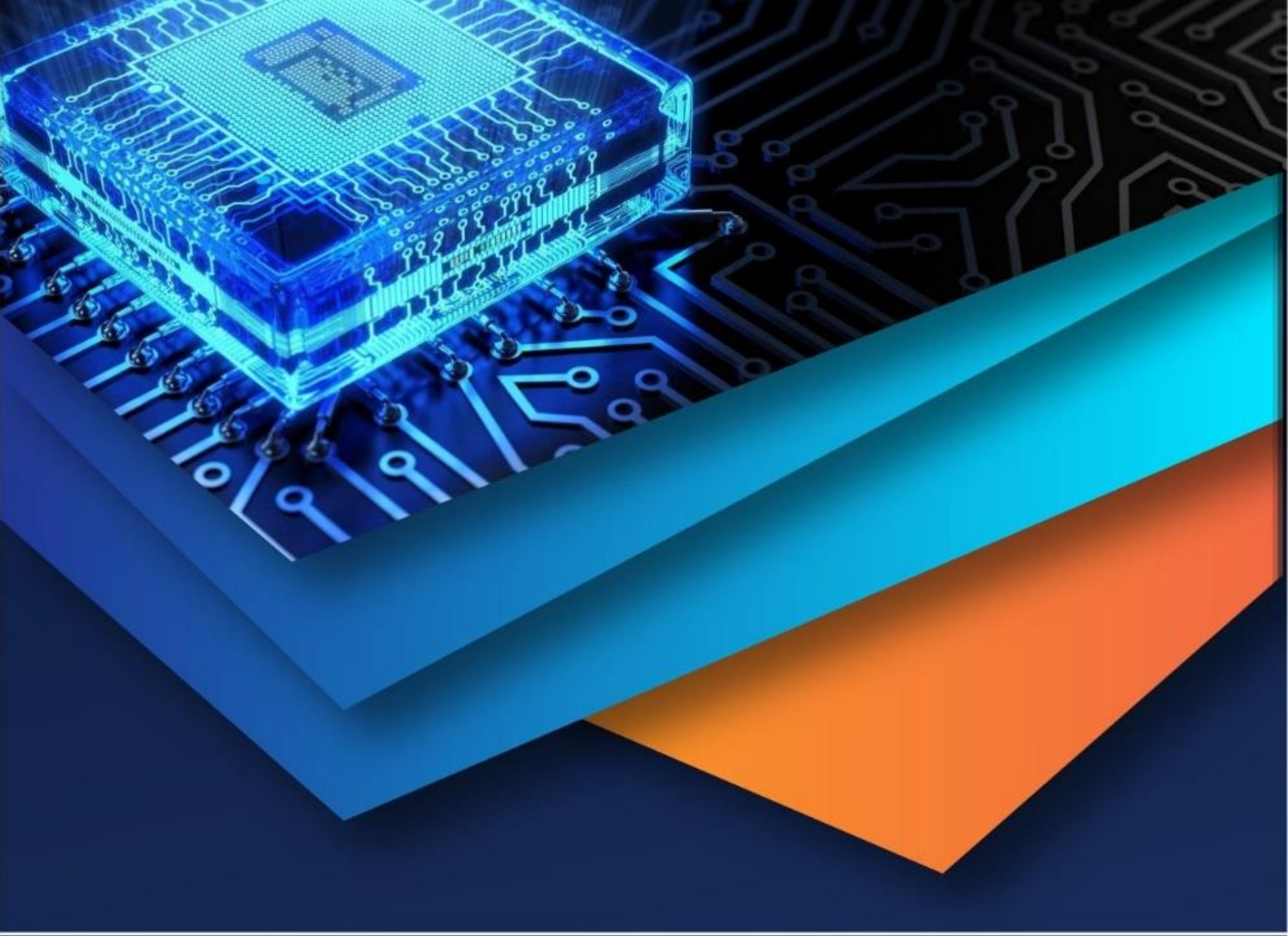

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