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Crack Monitoring in the Welding Parts of Different Alloys of Aluminium using Digital Image Correlation

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Abstract: Welding joints are directly or indirectly prone to different stress and strain damages. During the test performance of welding material the crack appears and these cracks continue to grow and then move from one surface region to another region. This load is continued to apply till the test fails. It is done to check the strength limit of the welded part. Also it is not easy to find the starting point where the cracks start to appear. There are various ways or techniques to find the cracks in the welded parts during the load tests. It includes ultrasound, thermography and use of strain gauges etc.

In this dissertation work a procedure for finding cracks in the welded parts after performing certain strength tests utilizing digital image correlation (DIC) method is proposed. The main benefit of this method is that one can find the cracks of macroscopic category and also monitoring can be done during performing of tests. Here digital images are captured during the different load cycles. As load applied is more than the strength of material cracks start appear to visible. So it is possible to find and detect the location of crack on the welded part. Since the digital images are stored in the database so it becomes easier for verification and comparison. This test is performed only for the cracks present on the surface of the welded material.

I. INTRODUCTION

A. Development

Welded joint on metals are easily accessible or prone to different types of fatigue damages. Different tests are performed to check the limit of the part under investigation. It is not easy to find when the crack appears to start. Even the residual stress and post weld treatments can affect the strength of welded material. Various methods are used worldwide for crack detection in mechanical materials like ultrasound rays, thermography and for crack length methods, potential drop and strain gauge etc are used. [1]

Digital image correlation (DIC) is well known for detection of different types of cracks on welded parts during fatigue tests. This correlation is used for identifying large cracks at the starting stage of tests performed and also used to monitor the life cycle of the crack appearance. This basically contains measurements of different strain fields at the weld location. Here digital images are taken at pre fixed time intervals. As more strain is applied then after certain limit the cracks start to appear. As camera is capturing all this process so the images of each moment is stored in the database. So it becomes easy to detect and find where the crack has been started to appear in the process. Also one can easily verify and compare the result also. [2]

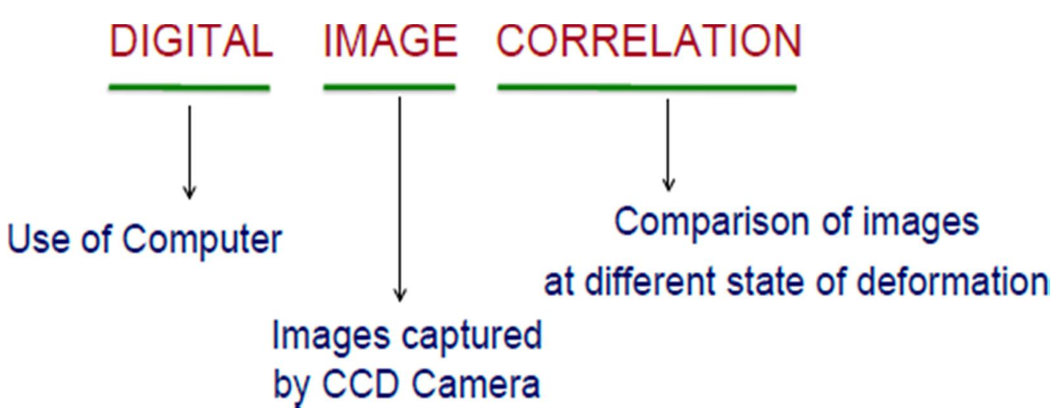

Figure 1.1: DIC overview [39]

This all process has a limitation that it can predict or check the cracks only at the surface of welded joint. So unlikely checking the crack manually the above process guides us to direct observation of cracks from their starting state till rupture of the part under investigation.

Figure 1.2: DIC is applied to find deformation, vibration and strain on material [38]

As the computational methods become more advance the digital image correlation becomes very important and famous technique for mechanical as well as civil industry and also for research applications. Main benefit of this process is that it is totally automatic and there is no need of manual labour and no expertise skill is required for performing this process. If manual testing is performed by using high magnification lenses then one can detect cracks but it becomes very hard to detect when and where cracks just starts to appear. But with the help of DIC method everything becomes handy. [3]

At present in the industry still old or traditional methods are used for detection of crack patterns in the material. The method which is generally used is visual inspection where the investigator estimates the crack width with the help of magnifier which has pre printed line widths. Also in various other experiments that deals with structures, mechanical strain gauges are used for finding crack location. With this method accuracy somewhat greater than the previous method which is using magnifier glass for crack width estimation is obtained. [4]

In another technique for crack estimation which uses already installed discrete stages at various test specific locations on the sample surface where the relative distance could be tracked. The target samples are arranged in a grid so that various crack at unknown locations can also be measured. With the help of this technique measure of sliding of crack as well as compressive strains can also be measured. But all of these techniques are manual and depend on the human skills and so very much prone to errors in measurement and also time consuming which can also affect the test procedure and also the structural behavior when the load is applied on the material. [3]

Further the materials which have low deformation capacity then measurement at near to failure of elements is not possible due to safety risk of the person as well the safety of machinery equipment. This type of problem can be solved by utilizing linear variable differential transformers (LVDTs) which are also known as linear displacement sensors. Also in case of optical crack tracking systems the displacement of the markers is measured by using optical tracking signal methodology which is joined on the concrete surface. All of these technologies gives more accurate results but due to limits in spatial discrete, information are not fully stable. So to get more accurate results as compared to these methodologies refined crack monitoring and measuring methods can be used that are used for detecting complex crack patterns. [6]

Image-based measurements also comes under this category. These methods can also extract information from the surface structures using digital images. Benefit of this methodology is that the camera which is used as an instrument is contactless and so it will not disturb the setup which is under testing. There are many crack measurement methodologies based on the digital images which can be direct as well as indirect. In case of direct measurement techniques, image processing methods use grayscale and color pixel values directly. In case of indirect crack measurement the outcomes received from digital image correlation (DIC) where the spatial variation in pixel values in the original and final deformed state are tracked by finding the relation between their neighbouring pixels. [7-8]

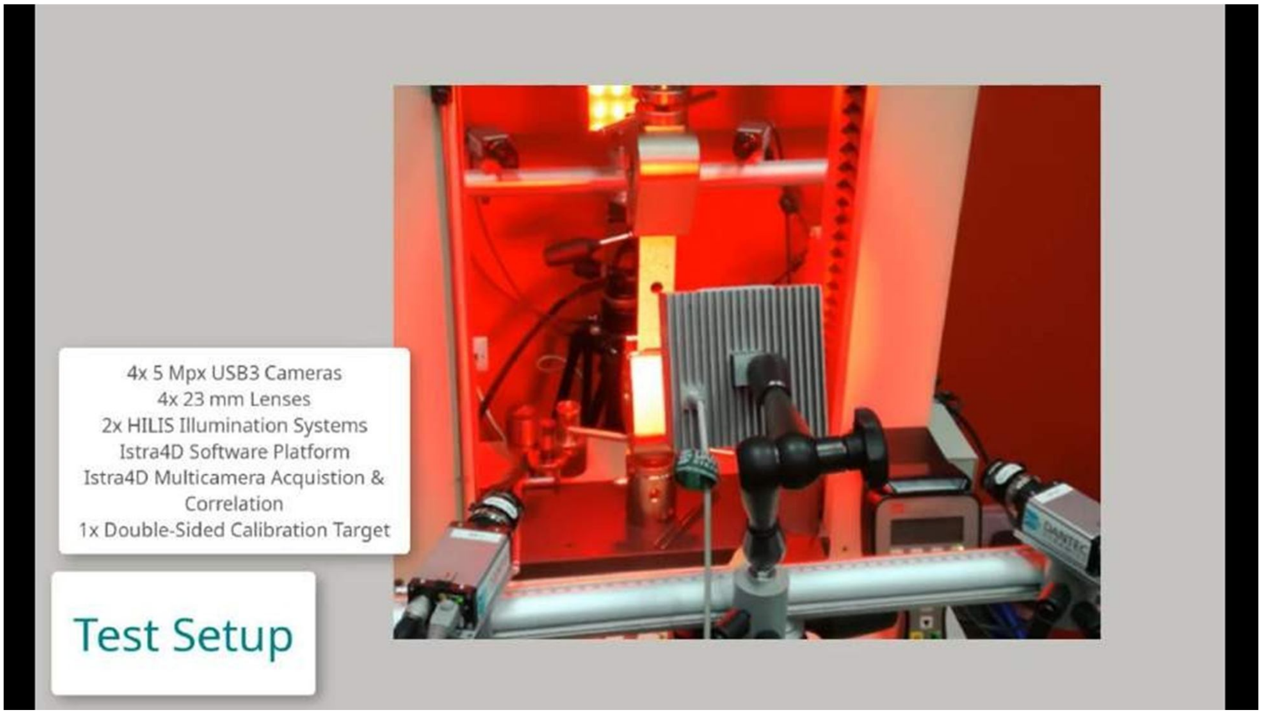

Figure 1.3: DIC test setup [38]

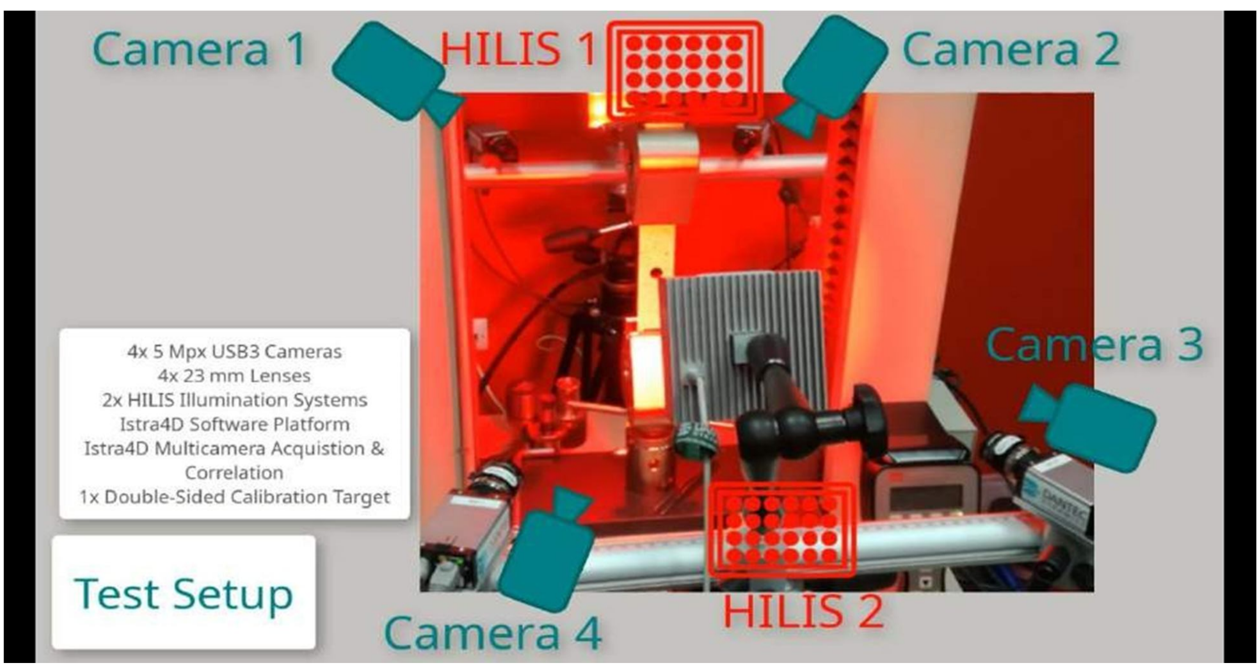

Figure 1.4: DIC test setup with highlighting camera positions [38]

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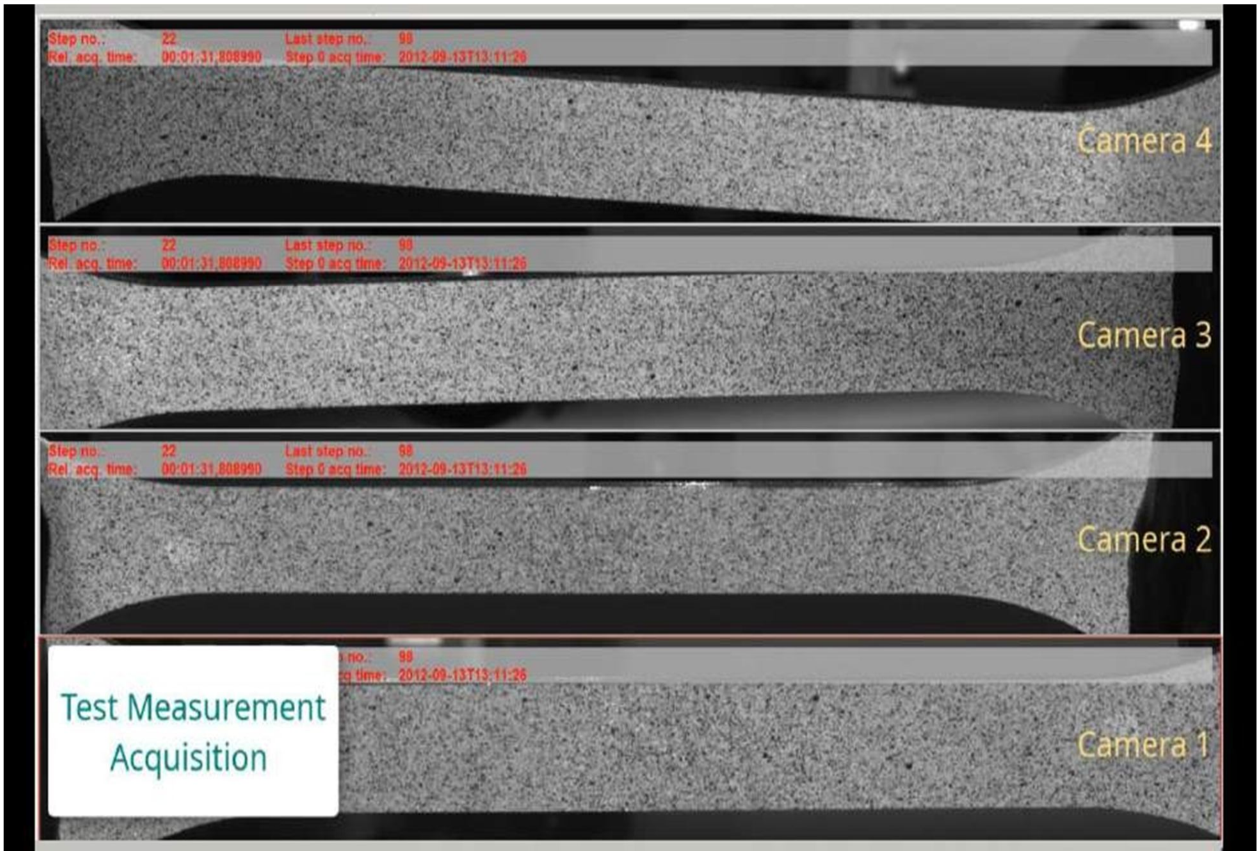

Figure 1.5: DIC test measurement with the four cameras at a particular instant at step no. 22 [38]

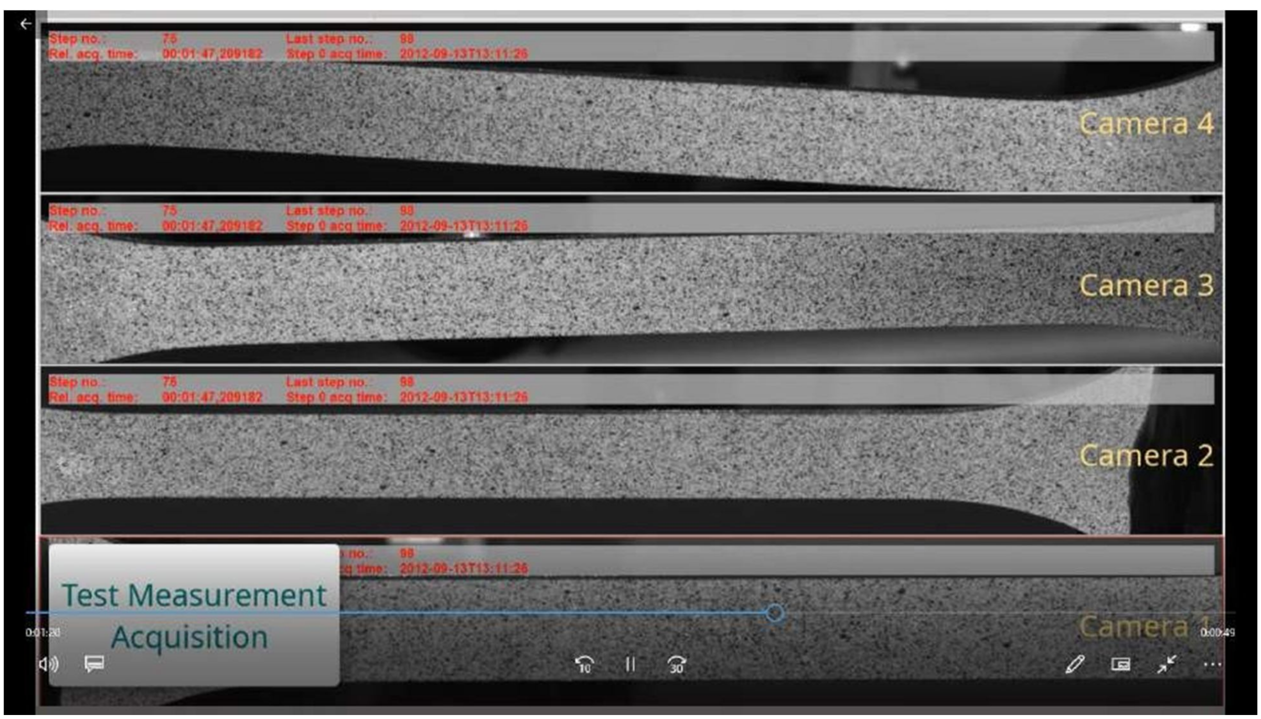

Figure 1.6: DIC test measurement with the four cameras at a particular instant at step no. 75 [38]

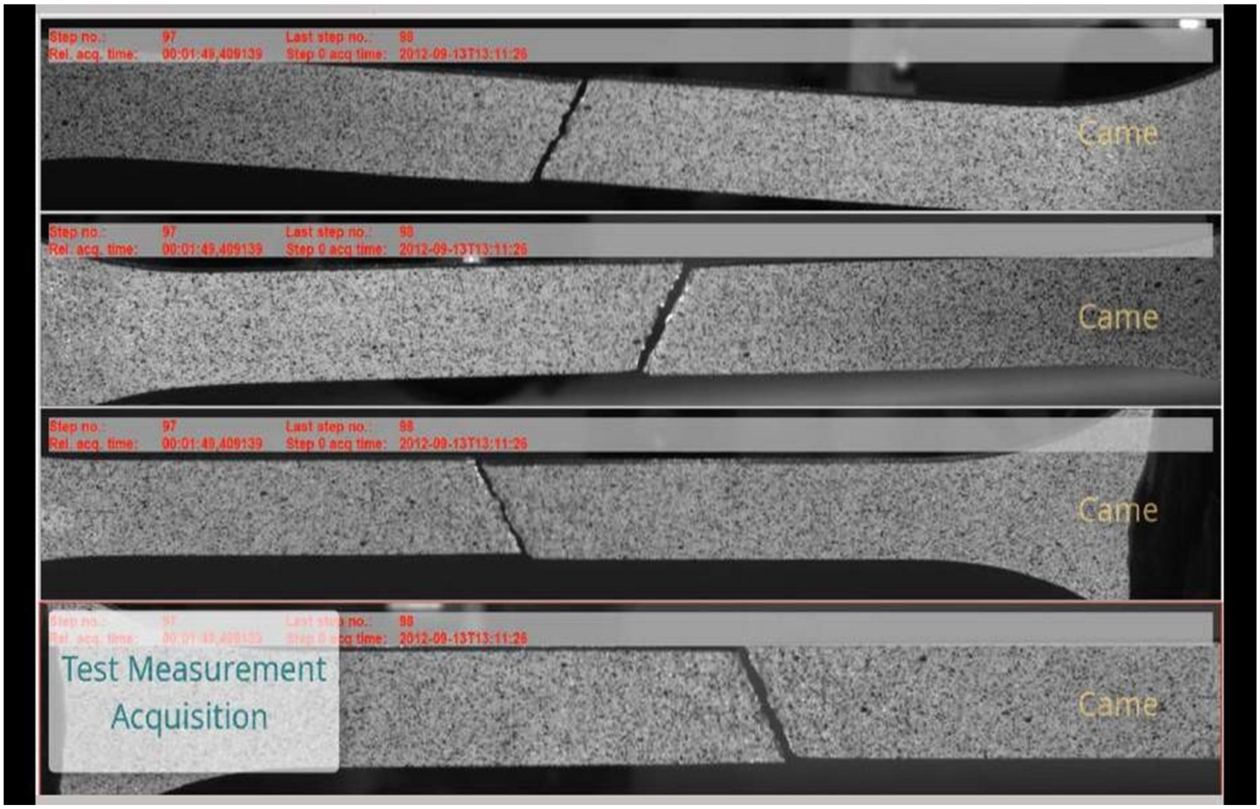

Figure 1.7: DIC test measurement with the four cameras at a particular instant at step no. 97 [38]

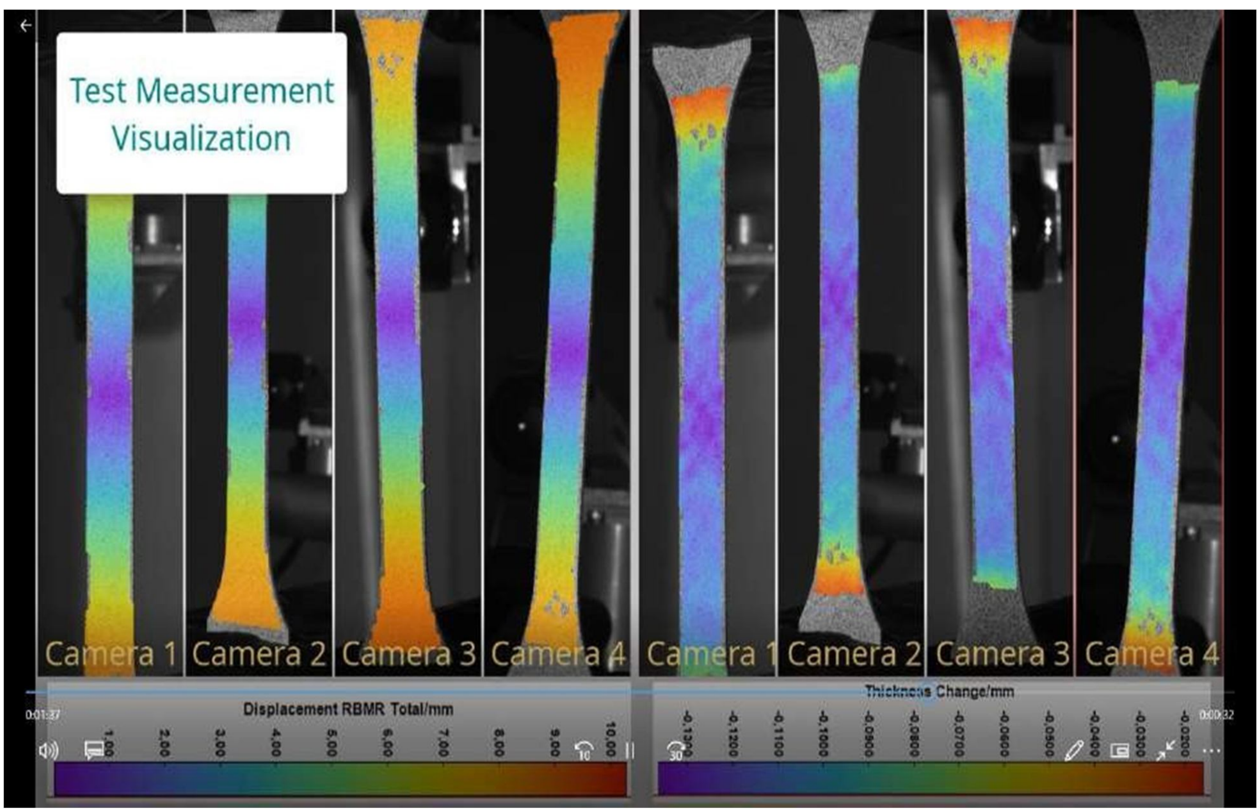

Figure 1.8: DIC test measurement energy visualization with the four cameras [38]

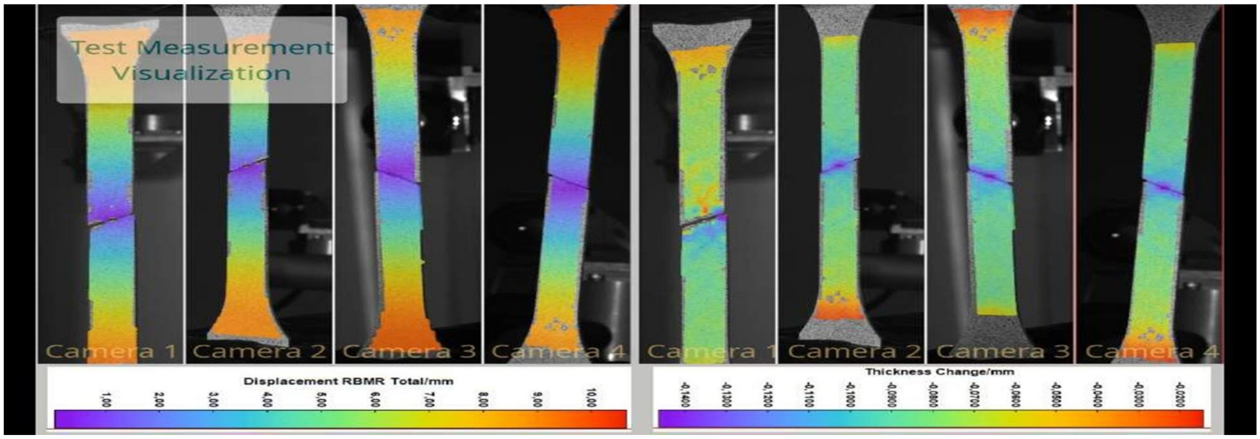

Figure 1.9: DIC test measurement energy visualization with the four cameras at breakdown [38]

As both of these methodologies need a very high resolution camera for extracting the crack patterns so camera sensors should have high resolution. As present methodologies are using the pixel values for finding the crack parameters for the existing structures. The pixels values are directly used for crack estimation for the existing structures as it requires no reference measurement. Benefits of the technique have motivated many researchers to develop various automatic crack detection methods utilizing image processing methods. [10]

These methods show good results in case of quantitative analysis based on objectivity while the visual crack estimation is very tedious and also dependent on the specialist person knowledge and experience also. The overall setup of the crack estimation using camera consist of high resolution camera, image denoising and enhancement filters, crack detection algorithms and crack feature extraction detectors. At present there are various crack detectors available whose theory is based on the the thresholding the background and foreground, morphological operators, various machine learning techniques. [11]

In these algorithms once the cracks are detected by the system then various crack objective features like length, width, inclination are calculated. The crack width is generally calculated by finding the minimum distance amid parallel crack lips which are estimated with edge segmentation methods. As these techniques use pixel values directly so these have high precision rate in controlled experiments. Now the crack detection algorithms are based on contrast and brightness present in the homogeneous region in the uncracked regions in comparison to high contrast where cracks are present. So the material specimen is usually painted in white color. [12]

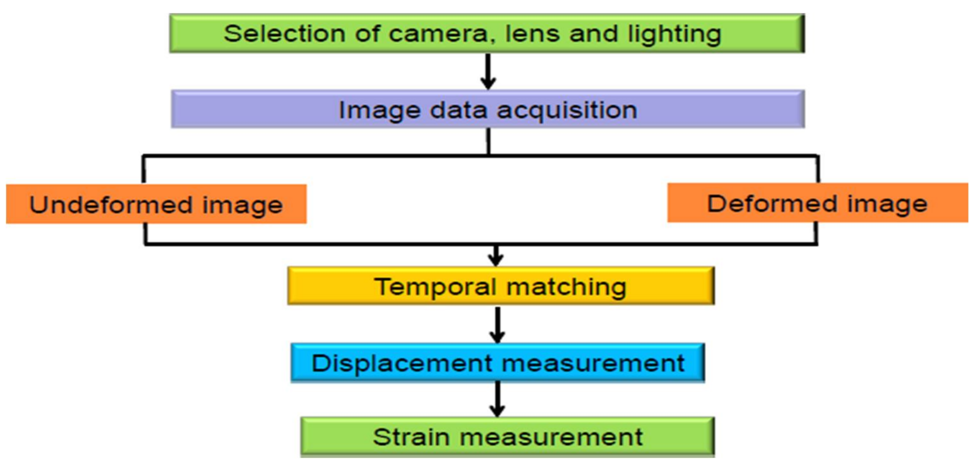

Figure 1.10: Two dimensional DIC flow chart [40]

Sometimes the paint can fill the cracks having smaller width so image processing relied methods for crack width estimation can work only when the setup has high magnification resolutions and there is no issue with the width requirement of cracks. Figure 1.10 shows that the flowchart of the digital image correlation mechanism. It consists of camera and their acquisition methodologies and then there is temporal matching and then displacement measurement. In the last state strain measurement is applied. [14]

B. Key Features Of Digital Image Correlation

1) 3-Dimensional complete field, real-time display of displacement as well as strain overlaid on live image.
2) Various camera system for around 360-degree measurement around an object and simultaneous both front as well as back side measurements.
3) Measurement area range varies from less than 1 mm to many square meters.
4) Very fast as well as quite easy automatic calibration method.
5) Online feedback of both the objective parameters of accuracy and quality.
6) All data with an error approximation.
7) Data is accessible in an open data format.
8) There is also synchronous saving of analog data.
9) There is export tool extended to FEA software to compare the results.
10) Various 2D as well as 3D coordinate systems.
11) Very powerful camera system to 1,000,000 frames/sec.

C. Applications Of Digital Image Correlation

Digital image correlation has various uses in the different industries :

1) Automotive
2) Aerospace
3) Biological
4) Industrial
5) Research
6) Education
7) Government and Military
8) Biomechanics
9) Electronics
10) Earthquake measurement for deformation mapping

D. Tungsten Inert Gas Welding

In the process of Tungsten Inert Gas Welding which is also known as TIG uses an electric arc amid the refractory electrode and the work piece which is made up of tungsten material. In this process any inert gas is used which helps to shield the electrode and protects the liquid pool against oxidation. Usually Argon is used for this process.

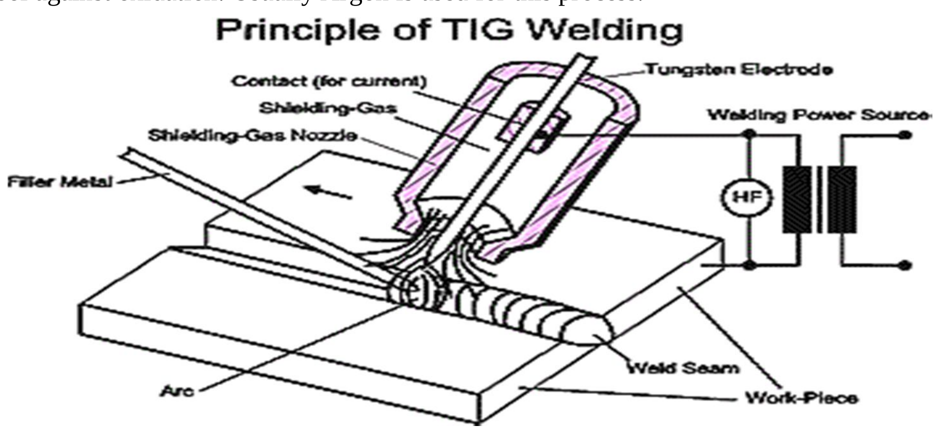

Figure 1.11: Tungsten inert gas welding [40]

Usually a power source which has very high frequency stabilized alternating current is utilized to provide the voltage. In this process alumina which is the oxide layer film is usually removed during the negative cycle and penetration as well as cooling of the electrode is done at the positive cycle. [40]

Usually tungsten inert gas welding (TIG) is suitable for those material and metals which have thickness amid 1 and 6 mm.

There are two types of tungsten inert gas welding.

1) *Manual Tig Welding:* Manual TIG testing is performed on those material or components which have very thin surface and small or also the circular welds. One of the benefit of this process is that in case of Manual TIG Welding if welding penetration is lower and work piece thickness is small then there is no need of filler material. If there is need of filler material then it could be introduced by manually or mechanically without the current or with half mechanically. Also this setup is lightweight as there are many compact as well as light TIG welding machine which has a weight of lower than 25kg are available to use. The setup is very easy to use as well as easy to carry and also this small and portable setup could also be used for repairing vehicles or other materials. [40]
2) *Automatic Tig Welding:* In case of Automatic Tungsten Inert Gas Welding the welding torch is moved automatically and also the filler material is fed to system with a reel which is also automatic in nature. This automatic welding process is usually employed for very large production mechanical systems like manufacturing of vehicles and other heavy machinery production. There is also an automatic tungsten inert gas welding version available where helium material is utilized as a shielding gas. Benefit of this gas is that it can achieve very high temperature in the arc. As alternating current is utilized in case of manual TIG welding but here direct current is utilized with straight polarity. This process can be used with materials which have thickness in the range from 0.2 upto 10 mm could be easily welded. [40]
3) *Applications of TIG*

Tungsten inert gas welding is applicable to usually all of the industrial sectors where there is need of high quality welding.

a) Stainless Steel and Non- Ferrous Metals such as Aluminium, Magnesium and Copper Alloys.
b) Aerospace.
c) Bicycle industry.
d) Piping.

II. LITERATURE SURVEY

A. Rezaie et al. [1] in 2020 performed a crack segmentation analysis on two methodologies where gray scale images were utilized to capture input digital images on stone walls of a masonry. For the first methodology author used digital image correlation (DIC) and after acquiring digital images from this process the prime strain map was calculated with the help of a threshold principle. In case of second methodology author proposed a neural network based approach. First of all input image is resized to 256 by 256 size. From the results author showed that value of dice coefficient and the precision of neural network based deep learning approach had given fine results as compared to the threshold technique. The value of third parameter which was precision had low value in case of deep learning as compared to the other method. From the outcomes of the experiment it was cleared that geometry of the cracked patterns of the material was preserved greatly by deep learning approach and the crack was strongly detected by this methodology in comparison to other methodology.

N. Gehri et al. [2] in 2020 used the digital image correlation (DIC) method for finding cracks as well as its measurement and all of this procedure was completely automatic. The DIC method was used for extraction of crack lines and showed the excellent results. The benefit of the proposed method was that it was based on the tensile strain field which helped to extract very fine cracks also in comparison to the methods which had used the pixel values methodologies. Both the widths as well as slips of the cracks were measured by the displacement field of DIC. Authors represented the visualization of crack process measurement with the smoothed data. Finally author had concluded that with the help of DIC one could find the accurate as well as high precision of the crack location as well as measurement even in case of very large and complex patterns of crack.

I. Tabiai et al. [3] in 2019 implemented a combined approach which was based on the digital image correlation and the image processing methodologies. The combined theory was practically applied to monitor digital cracks in a mechanically loaded system. The benefit of the proposed theory was that it could easily find as well as could track the present cracks in a special visualization which relied on the volume. The proposed approach was first applied to single fiber composite. Results showed that if the material possessed good fiber bonding then there would be slow growth in progress of crack.

The work also showed that the method could also be applied to any other process also. Author had used three parameters as objective parameters namely size, threshold, number of dilations. Author found that value of size parameter should be optimized between 0.4 and 0.75 otherwise if the size was small then it decreased the estimated crack area and if size was large then there would be overestimating of the cracked area. Threshold which was the second objective parameter applied to image entropy. The value of threshold was originally dependent on the speckle pattern quality. Last parameter used was the count of dilations. Here the value of count should be high so the complete crack part should be included. Further the optimized value of count in the experiment was found was 3. Overall the result of the experiment was satisfactory.

N. Friedrich et al. [4] in 2019 demonstrated a process which was fundamentally used for detecting the cracks. This procedure had also showed the procedure of crack growth and its speed along the process. Authors found that the prime problem in the process was the high load frequency of the used resonance testing machine. In this process there was very short exposure time and so it required high illumination to capture the image for performing DIC fatigue tests. Authors enlarged the aperture of the objective lens so that maximum light would enter the camera.

Authors found that after applying the procedure the strain measured by this method was not very accurate. Also these strains showed some very peak noise. But authors found that this method is very fast and with the help of strong precise procedure the cracks can be detected accurately and robustly with the help of DIC process.

C. Skotarek et al. [5] in 2019 tried to find the approximate value of damage appeared in the contact zone for a given load level. Authors further determined the accurate physical dimensions of pin a which was then transformed to a stl extension file. Now this file was imported into the FE-code ABAQUS. All of this process was simulated in simulation software with an insertion speed of 50 mm/min.

The mean cost of the contact stress values to nearly 100 MPa with the accurate cost was dependent on the detailed physical dimensions. In the proposed process there was no special element layer attributed to the contact region and so every element of the pin and the bore hole were touching to each other in the adhesive region. Authors found the shape was directly measured with the physical dimensions of the bore-hole and the pin in agreement with a real press-fit system. Result of the experiment indicated that the mechanical behavior of the system could be imagined quite well with the proposed prototype.

A. Muc et al. [10] in 2018 presented dual techniques for detecting cracks in the ship hulls. Proposed method was fully defined for structural health monitoring (SHM) of responsible welded joints of materials. All of proposed system was relied on the vibro diagnostic process. Here signals were detected with the help of piezoelectric accelerometers and also with the aid of fibre optic sensors. The main benefit of this method was its low cost. This method used two procedures. First one was spectrum analysis and other was time waveform.

Former procedure was based on measurement of average cost distribution with the help of time window. Later procedure was based on the damping parameter which decreased with time. Experiment results showed that both the above procedures differ quite significantly which further depend on the welding and showed their quality parameters and that signified the presence of crack in the material.

P. Corigliano et al. [11] in 2018 analyzed the fatigue behavior of titanium welded joints. Authors performed the welding with the help of a laser source and without the filler material. Authors used two techniques for investigation. First one was the Digital Image Correlation and other one was the Infrared Thermography. DIC technique tried to find the strain variation in the neighbouring region and cumulative damage. With the help of Infrared Thermography authors analyzed the surface temperature of welded joints and tried to find the strength of the invigilated welding joint. From the experiments authors found that fatigue strength could be identified at particular joint.

M. Koster et al. [27] in 2014 performed research on the brazed steel joints and substrate material. Author had introduced the steel in various heat treatments as well as in various geometries to investigate the fatigue behavior of steel. Authors performed various loading experiments on the servo hydraulic testing bench where R value was set at 0.1. When similar loading was applied at both the brazed specimen and on the substrate material then brazed steel had showed high value of plastic strain and low value of fatigue lifetime in comparison to substrate. Authors had used the digital image correlation (DIC) technique to find the local effects on the upper braze layer with the use of a very good speed camera. With the S-N curve author suggested that if the heat treatment was done after the brazing then it would significantly increase the fatigue lifetime as well as the defect tolerance. From the SEM experiments results showed that digital image correlation could be used for finding the cracks in the steel.

P. Lorenzino et al. [28] in 2014 presented an experimental methodology which used the procedure of digital image correlation (DIC) methods where various fatigue tests were performed in various types of resonant testing machines. These tests were conducted without any interruption. For this type of setup a USB type of optical microscope was used which had very narrow dimensions. The benefit of it was that it could be could be placed on the contact extensometer easily. With this type of setup while the testing machine is still in motion but the specimen which was subjected to fatigue would produce variation in the dimensions depending on the load applied. After performing various experiments and with continuous monitoring of the cracks growth of the specimens were flat in shape. Author had used the cylindrical type of notches of nearly 1000 alloys of aluminium. Authors got good results and also found that under specific conditions it was also possible that with the propagation of the crack one could also find that how it is possible for grain peripheries to act as a barrier for the propagation.

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III. PROBLEM FORMULATION

Welding joints are directly or indirectly prone to different stress and strain damages. During the test performance of welding material the crack appears and these cracks continue to grow and then move from one surface region to another region. This load is continued to apply till the test fails. It is done to check the strength limit of the welded part. Also it is not easy to find the starting point where the cracks started to appear. There are various ways or techniques to find the cracks in the welded parts during the load tests. It includes ultrasound, thermography and use of strain gauges etc.

In this work a procedure for finding cracks in the welded parts of aluminium alloys after performing certain strength tests utilizing digital image correlation (DIC) method is proposed. The benefit of the method is that one can find the cracks of macroscopic category easily and also monitoring can be done during performing of tests. The work was carried on Digital Image Correlation System, 230V, 50Hz 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 are described here :

1) Different welded alloys of same metal can have different weld strength.
2) At what strain value the weld quality becomes weak should be verified to save any accident.
3) Different fatigue test show different criteria for the quality of weld joints.

B. Research Objectives

This research work will be focused to achieve the following objectives :

1) To study and implement the crack monitoring of different alloys of aluminium using digital image correlation.
2) Process should be able to find the accurate position and time at which crack starts to appear.

V. RESEARCH METHODOLOGY

A. Research Methodology

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

1) Take different welded aluminium alloys.
2) Remove any unwanted material from the surface.
3) Perform the FSW and TIG welding on the metals.
4) Perform the different fatigue test with DIC process.
5) Check the parametric values of these welded alloys.
6) Check the accuracy of result obtained from the process.

In the proposed study welded parts obtained by friction stir welding and tungsten inert gas welding of aluminium alloys of AA6061-T4 and AA6061-O are studied. The joints obtained by these two types of welding are analyzed by applying tensile and fatigue strengths and hardness number.

B. Cracks in the Weld Metal

Metal cracks are broadly classified in the three types :

1) Transverse weld metal cracks are normal or say perpendicular to the direction of the weld. The transverse weld is most basic in welds that have a quite high degree of restraint.
2) Longitudinal weld cracks travel in the parallel direction as the weld moves. Mostly these type of cracks are found at the center of the weld. It is found that these type of cracks occur when the crack appears to start at the end of a weld.
3) Crater cracks are supposed to be appeared when there is an abrupt weld termination and it is due to any vacant crater left unfilled with weld metal. The appearance of these cracks is normally of star shape and at the starting point extends to the edge of the crater. Further it was found that such cracks can propagate into longitudinal weld cracks.

C. The Effect of Cracks on The Weld Integrity

In case of welded joints if cracks appear then these cracks are basically unacceptable in all forms and are supposed to be most dangerous to the performance of weld. It was found that the crack fundamentally is sharp at its ends and resulting behaves as a stress concentration. Further this type of effect of a crack is more than that of most other discontinuities.

Further if stress is applied to cracks then since the cracks have a nature to propagate and can so contribute to failure of weld. So in the fabrication, cracks whatever sizes are usually not permitted in weldments. So these cracks are normally removed by various mechanisms like grinding as well as gouging, or by the excavation filled with various types of sound weld metal.

D. Properties and Composition of AA6061-O AND AA6061–T4

Table 5.1: Chemical Composition of AA 6061-O

AA6061-O	
Component	Weight Percentage
Cu	0.15 - 0.4
Mg	0.8 - 1.2
Mn	0.15
Fe	0.7
Zn	0.25
Si	0.8
Ti	0.15
Others	Balance
Al	98.6

Table 5.2: Mechanical Properties of AA6061-O

Mechanical Property	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Hardness Number (BHN)	Elongation (%)
Base Metal	103	124	30	25.0-30.0

Table 5.3 Physical Properties of AA6061-O

Physical Property	Density (Kg/m^3)	Melting Point (^0C)	Modulus of Elasticity	Poisson's Ratio
Base Metal	2700	650	68.9	0.33

Table 5.4: Thermal Properties of AA6061-O

Thermal Property	Thermal Conductivity (MPa)	Thermal Capacity (J/KgK)	Coefficient of Thermal Expansion ($10^{-6}/^0C$)
Base Metal	180	896	24

Table 5.5: Mechanical Properties of AA6061-T4

Mechanical Property	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Hardness Number (BHN)	Elongation (%)
Base Metal	145	241	65	22

Table 5.6: Chemical Composition of AA 6061-T4

AA6061-T4	
Component	Weight Percentage
Cu	0.15 – 0.4
Mg	0.8 - 1.2
Mn	0.15
Fe	0.7
Zn	0.25
Si	0.8
Ti	0.15
Others	Balance
Al	98.6

Table 5.7 Physical Properties of AA6061-T4

Physical Property	Density (Kg/m^3)	Melting Point (^0C)	Modulus of Elasticity	Poisson's Ratio
Base Metal	2700	650	68.9	0.33

Table 5.8: Thermal Properties of AA6061-T4

Thermal Property	Thermal Conductivity (MPa)	Thermal Capacity (J/KgK)	Coefficient of Thermal Expansion ($10^{-6}/^0C$)
Base Metal	154	896	23.6

E. Algorithm for Crack Detection in Welding Parts Using DIC

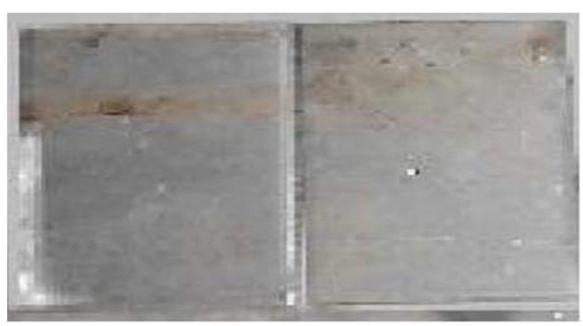
1) Take digital image of the cracked or uncracked part of welded joint of both FSW and TIG welding joints.
2) Perform filtering to remove noise and any unwanted thing from the surface.
3) Perform the segmentation.
4) Extract the features of welded parts.
5) Perform the feature matching.
6) Check for number of cracks present in the welded joints.
7) Store the results for manual investigation.

VI. RESULTS AND CONCLUSTION

A. Results

First of all different pairs of Aluminium Alloys of AA6061-O and AA6061-T4 are taken and their friction stir welding is applied on the pairs to get the FSW joints of both alloys.

(a)



(b)

(b) (d)

Figure 6.1(a, b, c, d): Pair of aluminium alloy plates of AA6061-O and AA6061-T4

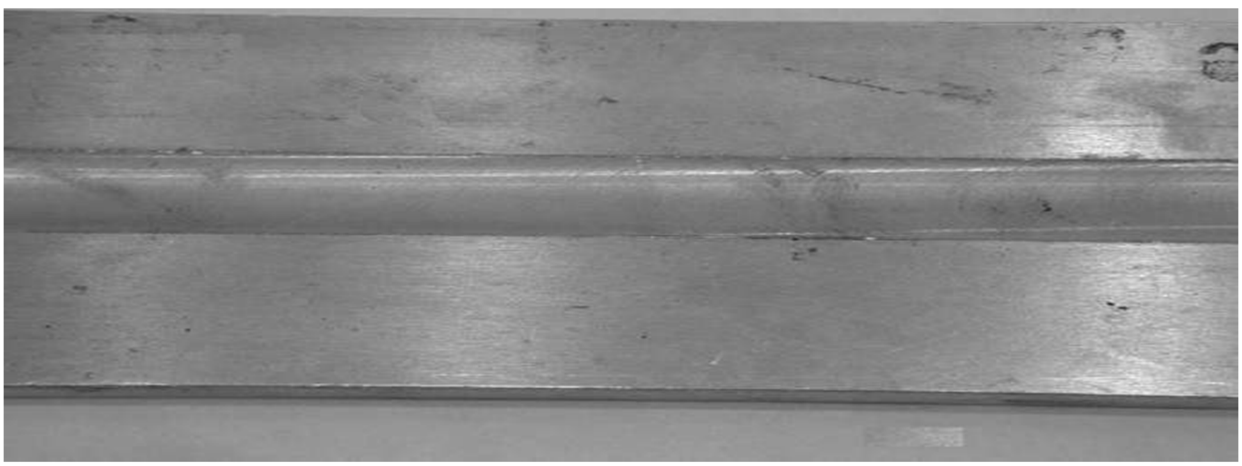


Figure 6.2: Friction stir welding product of figure 6.1 (a)

Figure 6.3: Friction stir welding product of figure 6.1 (b)

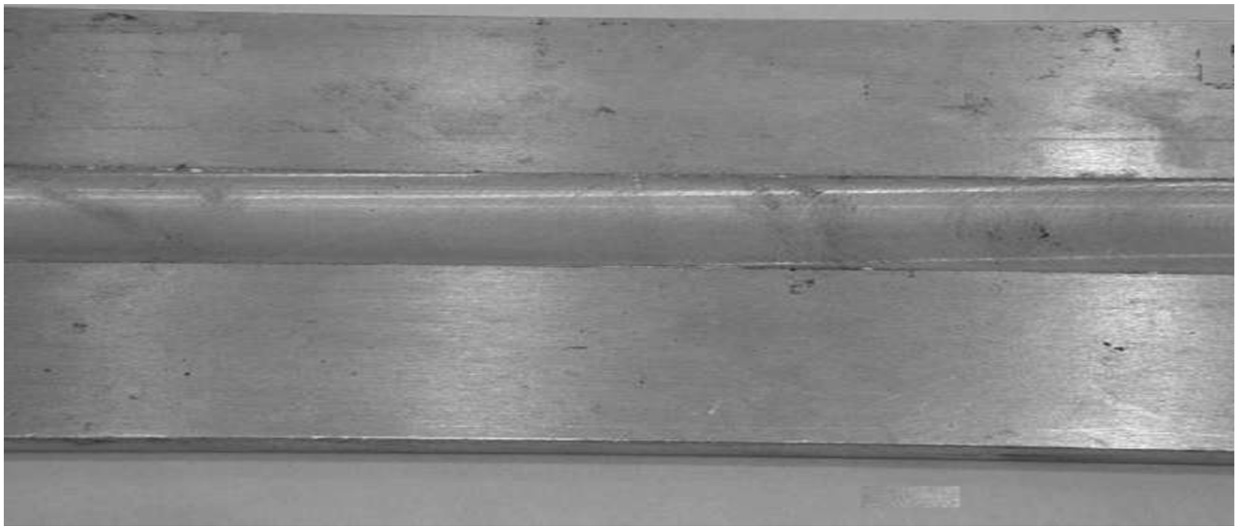


Figure 6.4: Friction stir welding product of figure 6.1 (c)

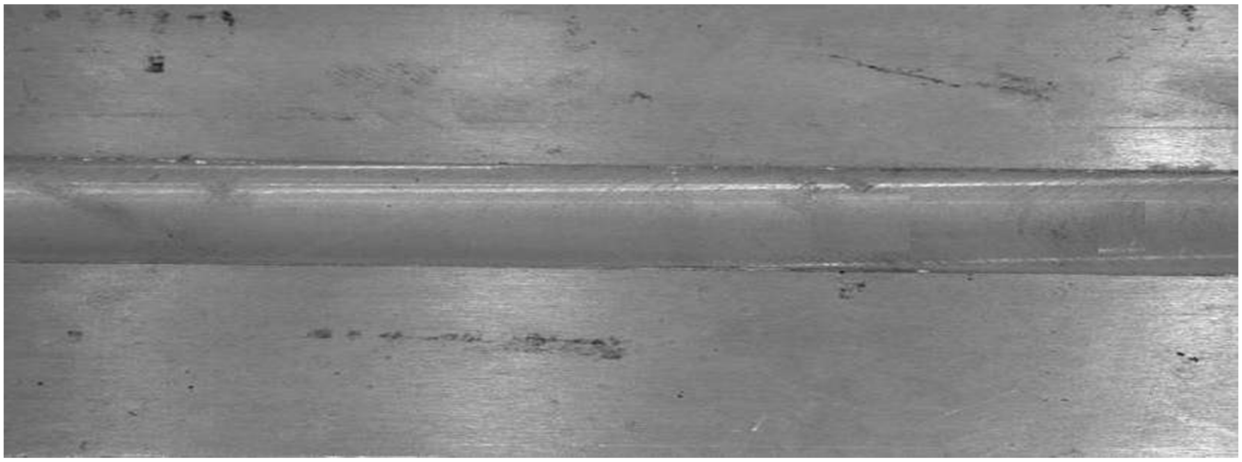


Figure 6.5: Friction stir welding product of figure 6.1 (d)

Figure 6.6: Friction stir welding product of AA6061-O and AA6061-T4 of first pair


Figure 6.7: Friction stir welding product of AA6061-O and AA6061-T4 of second pair


Figure 6.8: Friction stir welding product of AA6061-O and AA6061-T4 of third pair

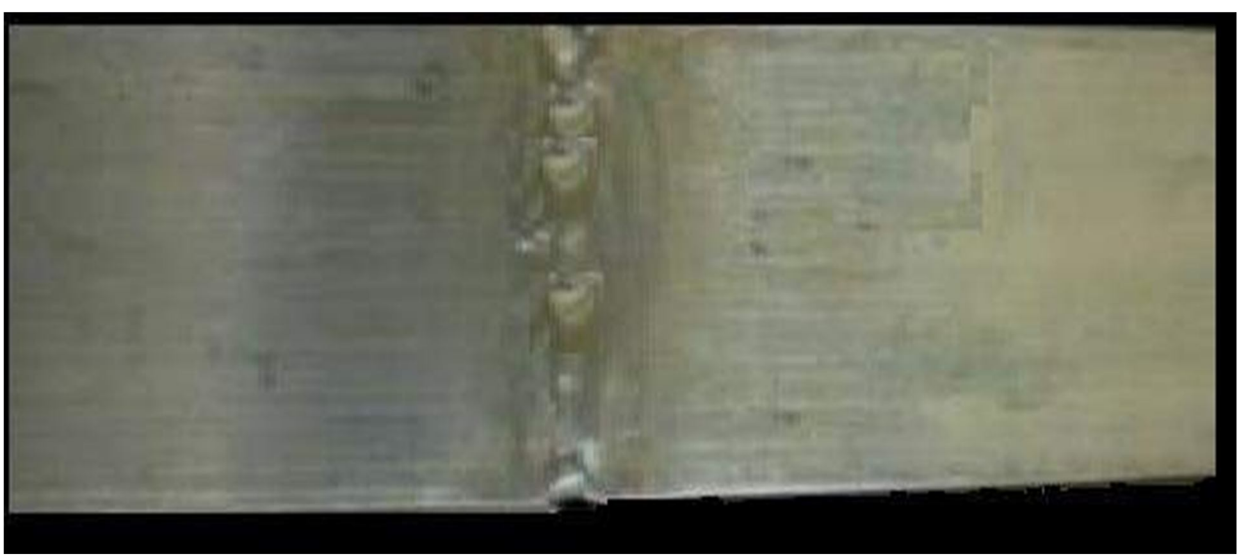


Figure 6.9: Friction stir welding product of AA6061-O and AA6061-T4 of fourth pair

B. Tensile Testing

Before applying the Tensile Test the sample specimens were prepared as per the required specifications. Load is applied with a speed of 1.1 mm/minute. After performing the tensile strength test on the pair of aluminium alloys of AA6061-O and AA6061-T4 it is found that the Friction Stir Welding perform better and defeats the TIG welding joints. It means friction stir welded joints have greater strength than the other welding joints.

Further it is found that TIG welded joints have high value of tensile stress at 115 ampere which is found to be 113 MPa. Also lowest tensile stress is found at 80 ampere which is found to be 68 MPa. While in case of friction stir welding joints of aluminium alloys the high value of tensile stress is 150 MPa which is found at 1000 revolutions per minute and lowest value of 15 MPa at 600 revolutions per minute. This is due to the reason that at 600 revolutions heat generated is very less so joints formed are weak.

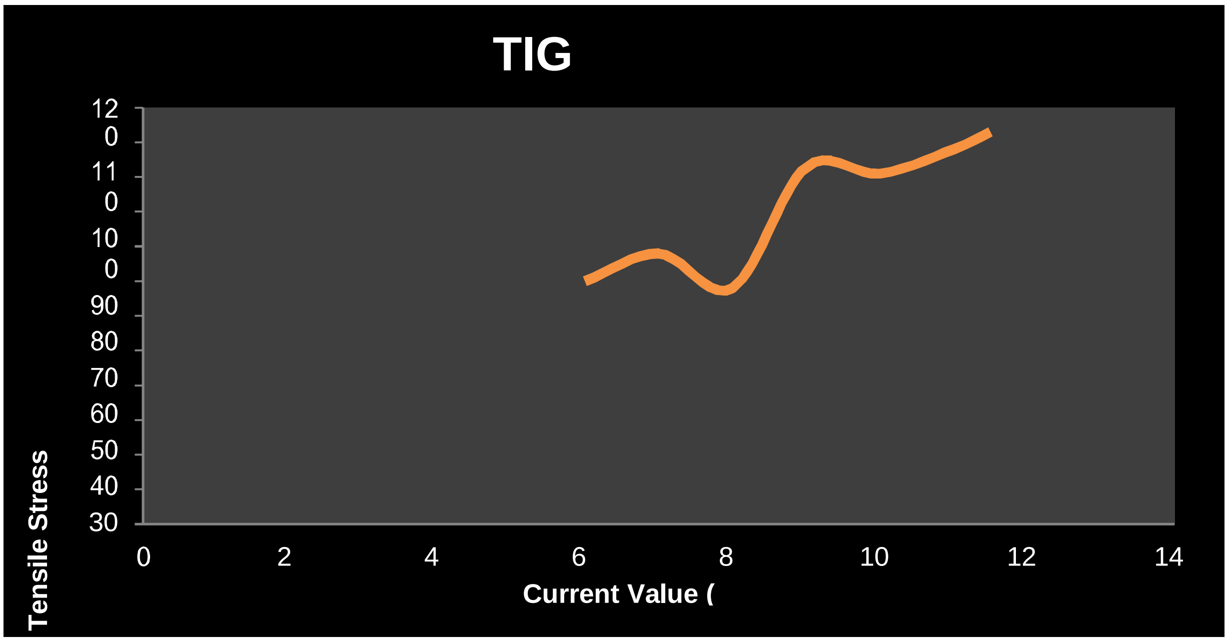


Figure 6.10: Graph plotted for tensile stress v/s current for TIG welding Table 6.1: Objective parameter values for TIG welding

S. No.	Current Applied (Ampere)	Tensile Stress (MPa)
1	60	70
2	70	78
3	80	68
4	90	103
5	100	101
6	110	108
7	115	113

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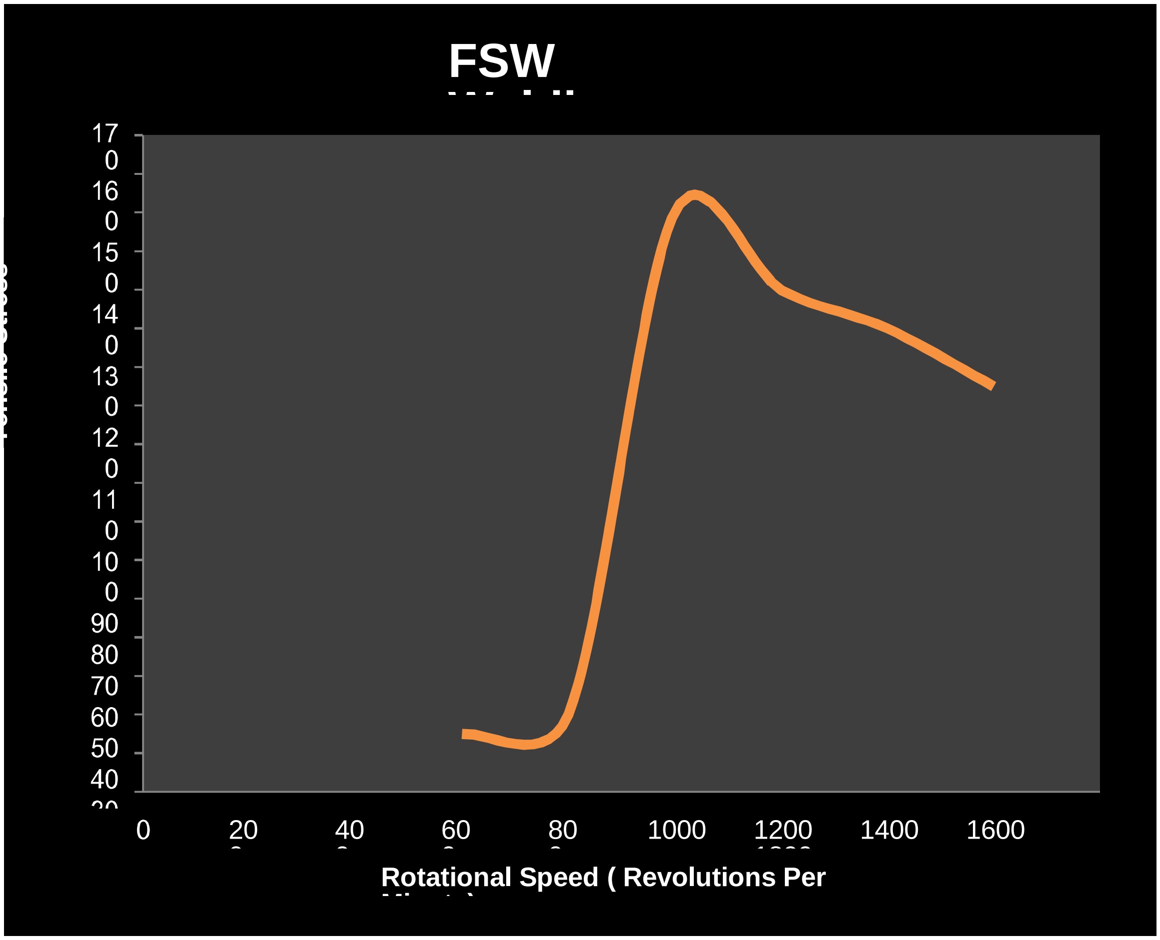

Figure 6.11: Graph plotted for tensile stress v/s rotational speed for FSW welding Table 6.2: Objective parameter values for FSW welding

S. No.	Rotational Speed (RPM)	Tensile Stress (MPa)
1	600	15
2	800	20
3	1000	150
4	1200	130
5	1400	120
6	1600	105

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C. Hardness Testing

Hardness Testing is performed with the help of Vicker's Testing Machine. Total load applied to the testing system is 11 kgf. Testing of strength is done such that the centre as well as both ends of the material are under load. Before starting the test various emery papers are used to clean the surfaces of the specimen on which testing is to be performed. Further it is found that TIG welding has highest strength at 115 ampere and value of hardness is 47 and has lowest strength at 80 ampere which is found to be 27 HV.

In case of friction stir welding the maximum value of hardness is found to be 49 which is found at 1000 revolutions per minute and lowest value is found at many instances. After comparing both tungsten inert gas welding and friction stir welding, the friction stir welding had an edge over the tungsten inert gas welding and hence wins the race.

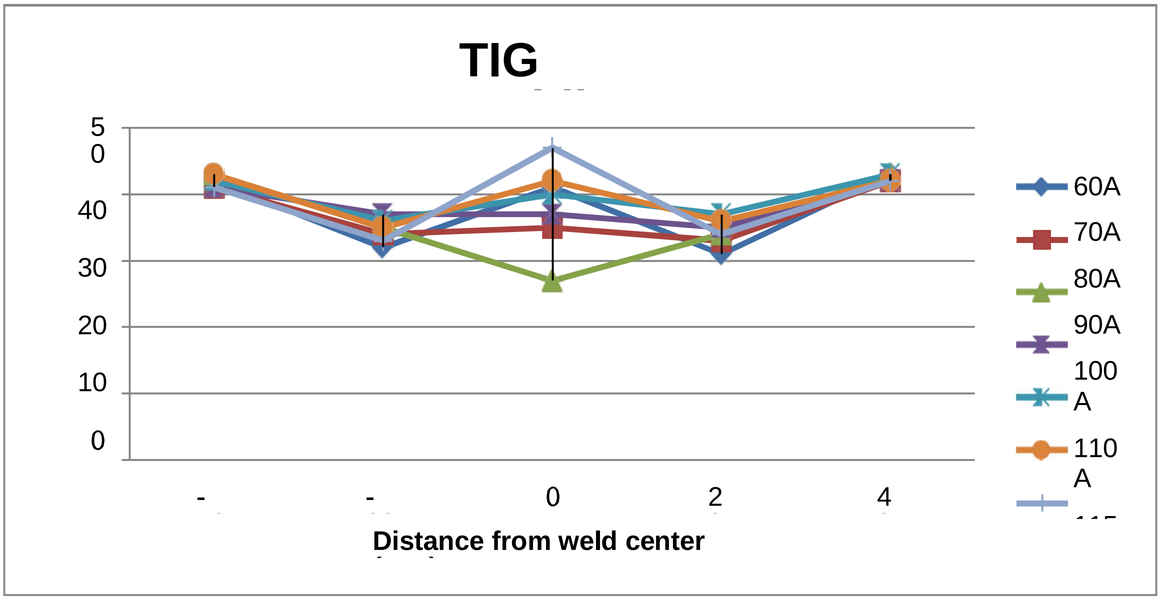

Figure 6.12: Hardness graph of TIG welding

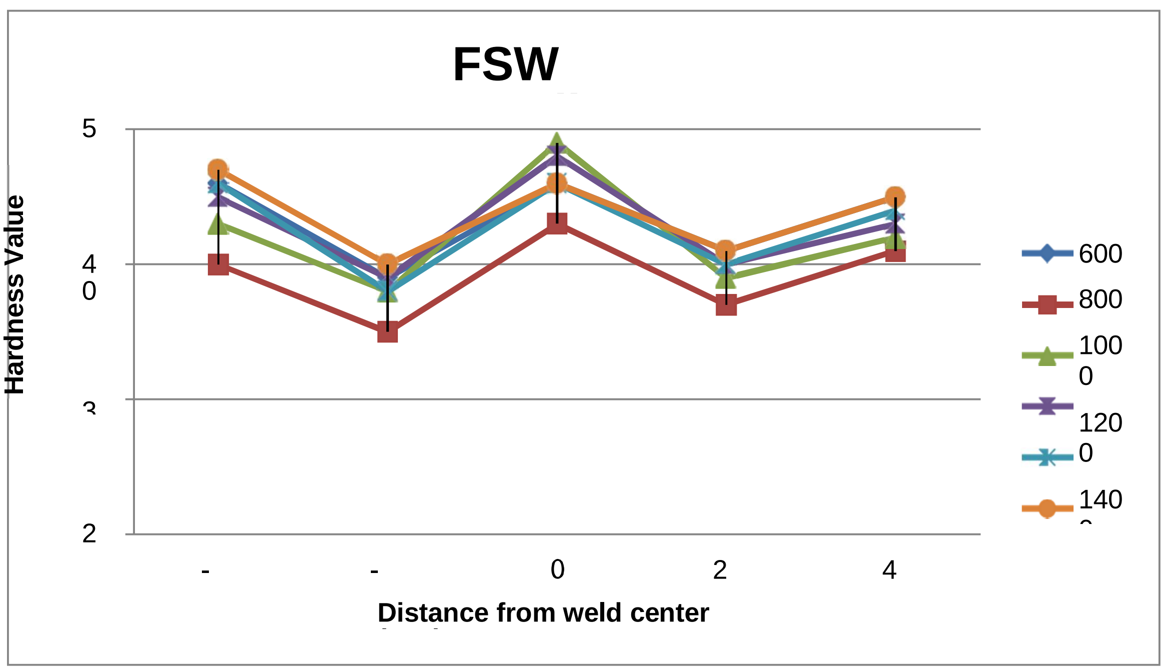

Figure 6.13: Hardness graph of FSW welding

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VII. ANALYSIS OF CRACKS BY DIGITAL IMAGE CORRELATION

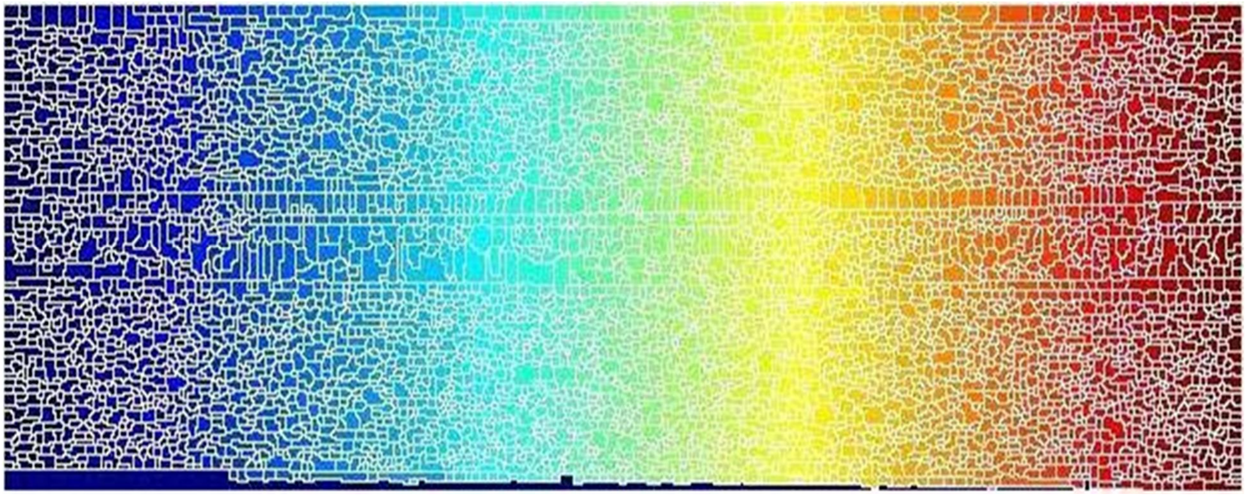

Figure 6.14: Original image analysis by DIC in FSW

Figure 6.15: Crack detection in image by DIC in FSW

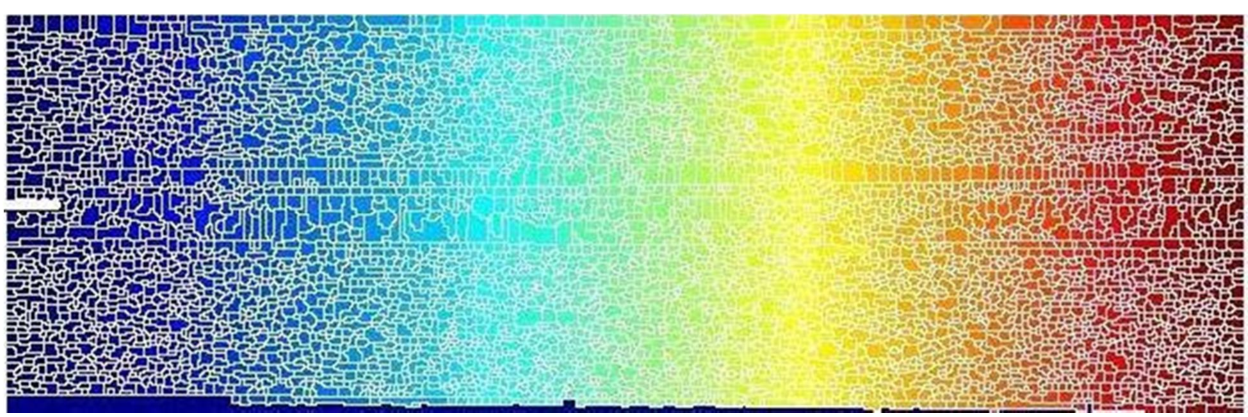

Figure 6.16: Crack pattern detection in image by DIC in FSW

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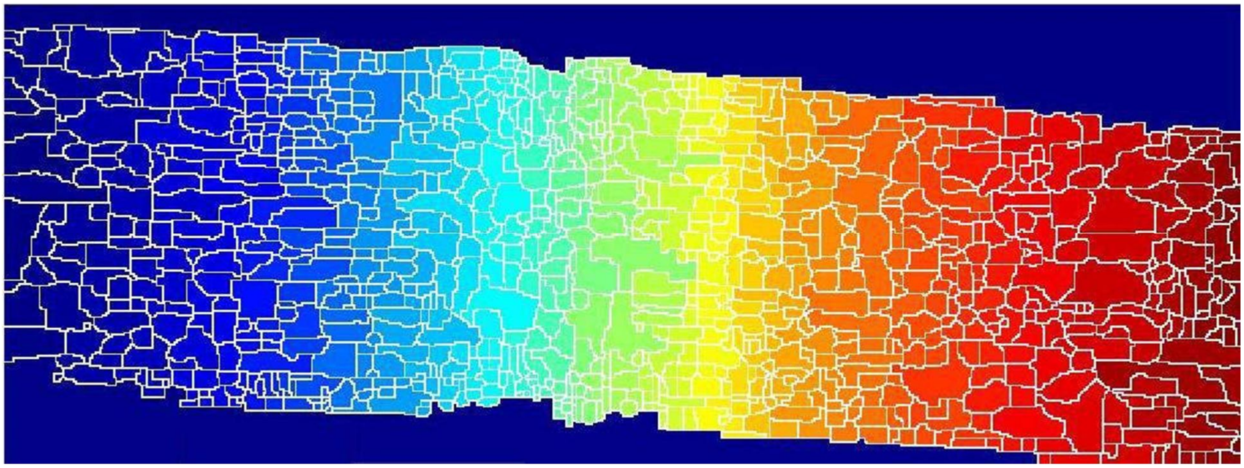

Figure 6.17: Original image analysis by DIC in FSW before plastic collapse

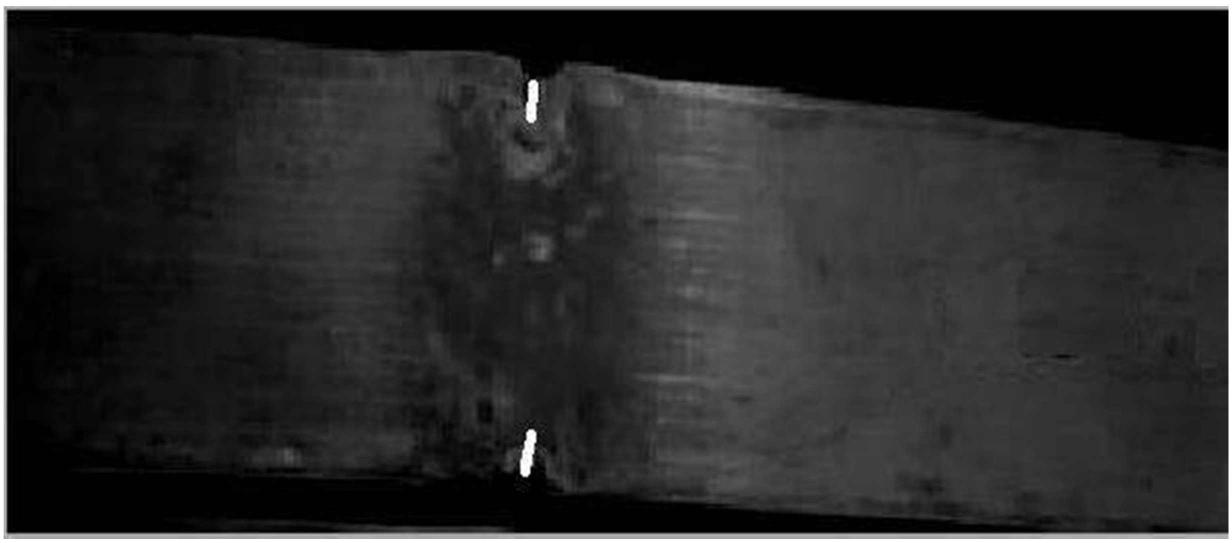

Figure 6.18: Crack detection in image by DIC in TIG

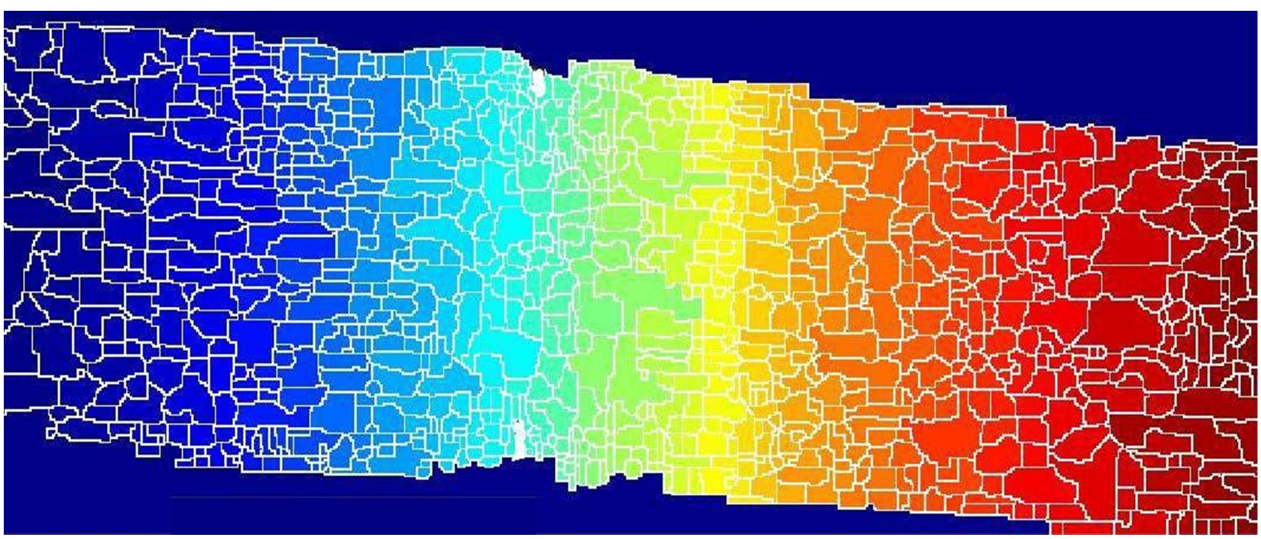

Figure 6.19: Crack pattern detection in image by DIC in TIG before plastic collapse

A. Conclusion

In this research work a comparison is made by comparing friction stir welding and tungsten inert gas welding on aluminium alloys of AA6061 -O and AA6061-T4. Further crack detection in the end is checked by the digital image correlation method. The results show that friction stir welding performs better in comparison to tungsten inert gas welding and also DIC method works perfectly to extract the cracks present in the welded parts after performing various strength tests on the specimen.

B. Future Work

In the future more emphasis can be done on various types of crack extraction and also the advanced system can be used to find out the internal characteristics of the material. Various other pair of other metals can also be taken for strength comparison and crack extraction can be done with the help of digital image correlation.

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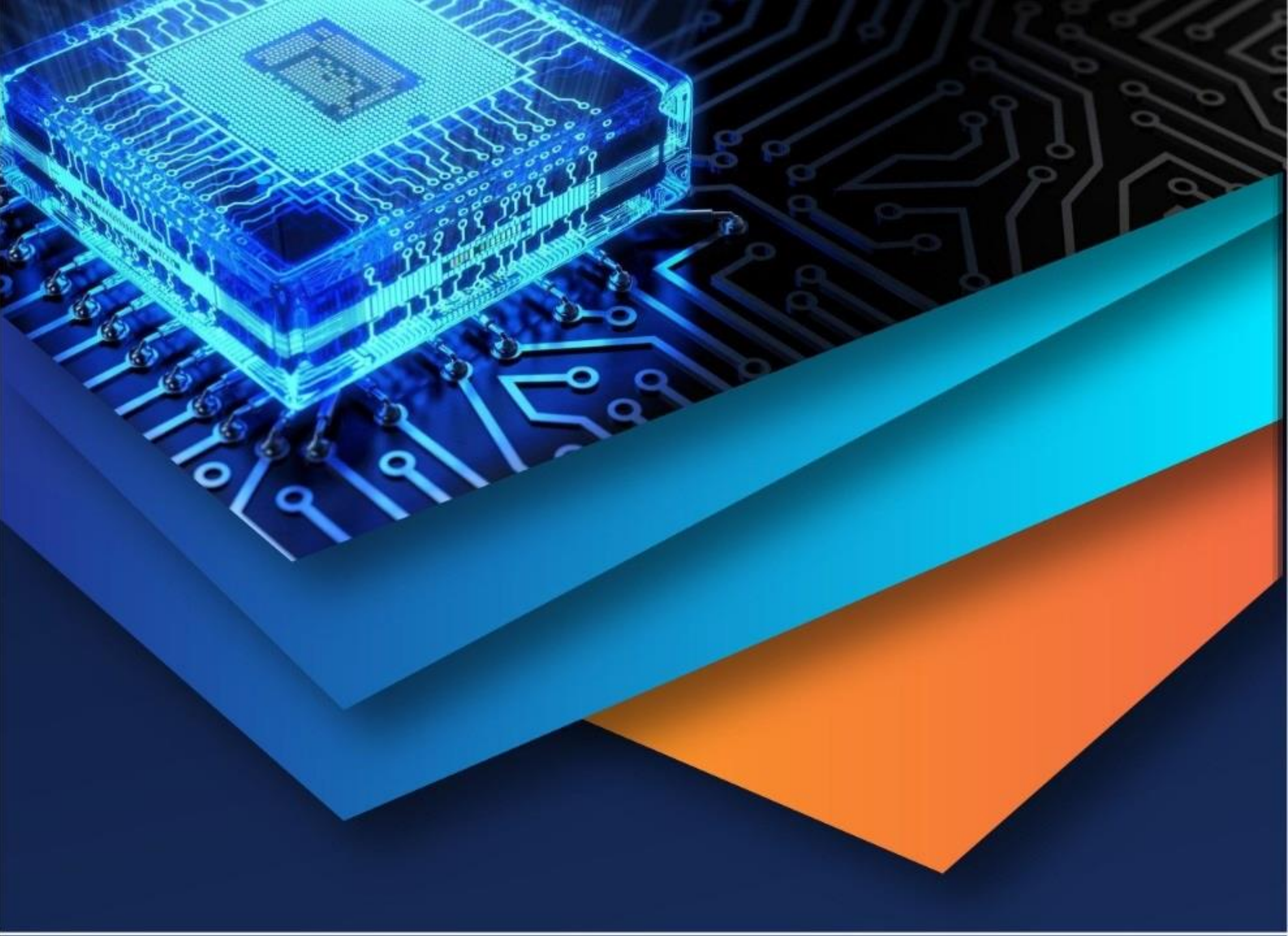

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