

International Journal of Circuit, Computing and Networking

E-ISSN: 2707-5931
P-ISSN: 2707-5923
IJCCN 2021; 2(2): 47-54
Received: 25-04-2021
Accepted: 10-05-2021

S Venkadesh
Department of Mechanical
Engineering, Thiagarajar
College of Engineering, Tamil
Nadu, India

M Shunmathi
Department of Mechanical
Engineering, Thiagarajar
College of Engineering, Tamil
Nadu, India

Corresponding Author:
S Venkadesh
Department of Mechanical
Engineering, Thiagarajar
College of Engineering, Tamil
Nadu, India

Friction stir welding of AA2024 and AA6061 using various pin profile

S Venkadesh and M Shunmathi

DOI: <https://doi.org/10.33545/27075923.2021.v2.i2a.37>

Abstract

The research work deals with to join two dissimilar aluminum alloys by solid state welding process compared to fusion welding processes and compared with fusion welding process, fusion welds tend to produce more defects while joining dissimilar materials. The major problem of the two dissimilar metals involve in welding process have different mechanical properties and microstructures which in turn may affect welding parameters like weld current, hold time, weld force etc. In order to overcome these issues, Friction Stir Welding (FSW) can be used to get rid of defects since it uses a non-consumable tool and also produces defect free welds compared to other welding processes. This thesis work aims to joining an aluminum alloy of 2024 and aluminum alloy of 6061. The plates are joined by means of octagon probe tool made of high carbon high chromium steel (D2 tool steel). Other issues while welding dissimilar aluminum alloys are phase transformation change and selection of welding parameters (rotational speed, transvers speed, pin diameter, shoulder diameter, D/d ratio and etc.) From conducted trail experiment aluminum alloy of 2024 and aluminum alloy of 6061 by using octagon probe tool made by HC-HCR tool it was observed that a lower welding speed 500 rpm at starting stage lack of filling took place and after thermo-mechanical heating took place that produce better weld while compared to weld at higher speeds (710 rpm, and 1000 rpm) with same transvers speed of 20 mm/min.

Keywords: AA2024, AA6061, Friction Stir Welding

Introduction

In the past two decades friction stir welding has been evolved as a successful welding technique for joining all hard materials and metal matrix composites in addition to aluminium. This is possible because, joining is established by means grain refinement which will also lead to increase in mechanical properties. During joining, the number of parameters required to control is limited and which can be easily controlled to produce the sound weld. Machine controllable parameters are having direct proportional relation with mechanical properties except welding speed. FSP and FSSW are the two variants in friction stir welding. Former can become a successful method to produce surface composites, super plastic forming, later can be a good alternate method to resistance spot welding ^[1]. Friction stir welding joints are prone to different types of defects which we can eliminate by choosing the proper tool design and process parameters. This process is less tried to weld hard materials due to the Lack of tool material and tool design. Tool wear will be the major problem while welding the metal matrix composites due to the presence of hard ceramic particles. More work has to be done in online monitoring of the process, online defect detection, controlling the temperature during the process. This paper is a review of research work in the last decade on friction stir welding ^[2]. Research is going on to investigate the effect of various process parameters on quality of the welded joint. In this study, the investigation is made on the effect of various process parameters, such as tool rotational speed, traverse speed, axial force and tool geometry on the quality of the welded joint are reviewed ^[3]. Yield strength, ultimate strength, elongation, toughness, microstructure of the joint are evaluated and correlated with received base material. To compare and validate experimental results, FEA model is the best way to study the quality of welded joint. Tool rotation speed, traverse speed, axial force and tool design are the most significant process parameters in friction stir welding. This paper is a review of research work in the last decade on friction stir welding. Research is going on to investigate the effect of various process parameters on quality of the welded joint. In this study, the investigation is made on the effect of various process parameters, such as tool rotational speed, traverse speed, axial force and tool geometry on the quality of the welded joint are reviewed.

Yield strength, ultimate strength, elongation, toughness, microstructure of the joint are evaluated and correlated with received base material [4]. To compare and validate experimental results, FEA model is the best way to study the quality of welded joint. In friction stir welding Cost effective and long life tools are available for the FSW of aluminium and other soft alloys. They are needed but not currently available for the commercial application of FSW to high strength materials. Tool material properties such as strength, fracture toughness, hardness, thermal conductivity and thermal expansion coefficient affect the weld quality, tool wear and performance. Reactivity of tool material with oxygen from the atmosphere and with the work piece is also an important consideration. Further developments in FSW tool materials are required to address the problem of high tool cost with low tool life during welding of harder alloy. Heat generation rate and plastic flow in the work piece are affected by the shape and size of the tool shoulder and pin. Although the tool design affects weld proper-ties, defects and the forces on the tool, they are currently designed empirically by trial and error. Work on the systematic design of tools using scientific principles is just beginning. Examples of recent studies include calculation of flow fields for different tool geometries and the calculation of tool shoulder dimensions based on the tool's grip of the plasticised material [5]. The pin cross-sectional geometry and surface features such as threads influence the heat generation rates, axial forces on the tool and material flow. Tool wear, deformation and failure are also much more prominent in the tool pin compared with the tool shoulder. The axial, longitudinal and lateral forces on the tool can be calculated as functions of process parameters, or evaluated from the measure data. Estimation of the load bearing ability of the tool pin is needed considering the maximum stresses in the tool pin due to combined effects of bending and torsion. There is a need for concerted research efforts towards development of cost effective durable tools for commercial application of FSW to hard engineering alloys. Friction stir welding process is used for joining material such as Aluminium, copper, magnesium etc., which are otherwise difficult to weld by the conventional welding processes [6]. The tool pin profile plays a critical role in determining the end properties of the welding joint apart from other parameter like rotation speed, traverse speed, welding speed, and axial load. The purpose of the investigations was to elaborate a set of FSW parameters for connecting 6061 aluminium alloy sheets allowing to produce welds of highest strength. The results of present experiments are adding new information on FSW of the aluminium alloys, especially 6061 type. The applied welding parameters provide good quality of welds [7]. The research aim behind. In analysis we use AA6061 similar material for flow stress, temperature and pressure analysis with Hyper works 9.0. Friction stir welding is the renowned technology widely used for joining materials. It avoids many of the common problems that persist in fusion welding. It is most suitable for joining soft materials like Aluminium and Magnesium alloys. Though this technology has been proven commercially feasible for soft materials, the same for harder alloys is yet to be established. The development of cost effective and durable tools, which lead to structurally sound welds, is still awaited. Material selection and design intensely affect the performance the tools [8] Investigation effort has been made for newer

compositions of heavy alloy tool manufactured through powder metallurgy route. Establishing welding parameters such as tool rotations speed, traverse speed and various mechanical properties of Heavy alloy tool by numerical analysis and computational fluid dynamics model predicted values from it. Heavy alloy tool is suitable for cost effective and durable tool in hard alloys such as stainless steel. The present paper focus on the finite element simulation of the friction stir welding (FSW) of AA4047 Aluminium plates based on the commercial numerical codes of Altair Hyper works with an objective to investigate the complex interaction of thermo- mechanical process characteristics of FSW [9]. A 3D finite element model (FEM) heat transfer model has been proposed and temperature and pressure distribution along with the variation of flow stress during the welding of plates was critically investigated. Also, Taguchi L9 orthogonal array technique was used to optimize the process parameters for obtaining defect-free high-quality welds. It is expected that the present work will be useful for understanding the underlying physics and thermo-mechanical mechanism of FSW [10]. It can be concluded that by varying the process parameters within the range: Case I: Tool rotation speed 1120 rpm, Welding speed 20 mm/min and Pin length of the tool 5.2mm. Tensile strength obtained is 142Mpa. Case II: Tool rotation speed 1400 rpm, Welding speed 25 mm/min and Pin length of the tool 5.7mm. Tensile strength obtained is 182Mpa. From the two cases it has been observed that the maximum tensile strength obtained is 182 Mpa from case II. We know that tensile strength of base material is 320Mpa; it means the joint efficiency is 60%. The problems of weld defects like voids, cracks, distortion are still representing a serious headache to the researchers in the welding community [11]. This article is a preliminary study to adapt the tools, machine parameters and the work piece. It aims to examine the effect of probe rotational speed on the mechanical and micro structural properties of the weld joints. In fact this research is a part of a comprehensive research comprises the effect of probe profile, shape, pin length, traverse speed, preheating, tilt angle, applied load and heat transfer parameters on FSW of Al alloys [12]. Advanced Four different regions were distinguished in Al-Al FSW process, the NZ, TMAZ, HAZ and the BM. Controlling the welding parameters particularly the rotation speed and the probe design has yield sound and defect free weldments. The NZ showed lower hardness value as opposed to that of the base metal indicating multiple contradiction effects of work hardening, softening and grain refinement acting simultaneously. However, at rotational speed of 1500 rpm the weld joint showed no sign of surface defect such as porosities, cracks and inclusions. The outcome was weld joints of strength higher than that of the base metal. Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December 1991. Initially, the process was regarded as a "laboratory" curiosity, but it soon became clear that FSW offers numerous benefits in the fabrication of aluminium products. Friction Stir Welding (FSW) has become a major joining process in the aerospace, railway and ship building industries especially in the fabrication of aluminium alloys. The process uses a spinning non- consumable tool to generate frictional heat in the work piece. Worldwide, there are now over 135 licensees of FSW and new techniques and

applications are being developed daily [13]. This paper looks at the review, on friction stir welding process, various welding variables like tool rotation, transverse speed, tool tilt, plunge depth and tool design, for the welding of aluminium alloys or various dissimilar alloys. Applications, future aspects and several key problems are also described [14]. The present review has demonstrated the extensive research effort that continues to progress the understanding of FSW of aluminium alloys and its influence on their microstructure and properties. It identifies a number of areas that are worthwhile for further study. From an engineering perspective, there is a need to investigate the occurrence and significance of flaws in friction stir welds. In particular, the influence of tool design on flaw occurrence and the development of non-destructive testing techniques to identify flaws in both lap and butt welds would be beneficial. Metal flow modelling may have a role to play here, though capturing this aspect of the thermomechanical behaviour remains a significant challenges [15].

2. Problem description

The aim of research is to join the dissimilar aluminum alloy AA2024 and AA6061 using various pin profile octagon probe tool using in friction stir welding method. The weld quality and joint integration will be qualified through the mechanical properties.

2.1 Objective

- To weld dissimilar metal like AA2024 and AA6061 is to be change the design of tool. It can be done by change the Shoulder diameter (SD), pin diameter (PD), pin length (PL) and profile.
- To study and measure the mechanical property like tensile strength, hardness of the weld and optimize the process parameter.

2.2 Research method

Process parameters such as welding speed and feed must be monitored and evaluated to obtain various comparisons between process characteristics and welded material characteristics. The base materials are two dissimilar material like aluminum alloy 2024 and aluminum alloy 6061 by used the friction stir welding with various pin profiles. The dissimilar material dimensions are 50mm×100mm×6mm of each plate and the type of joint consider as butt joint, tool geometry selected in octagon pin profile, where tool is made up of high carbon high chromium steel (HC-HCR). The experimental equipment needed to effectively carry out the characterization of the weld properties. Many Friction Stir Welding process parameters are variables and they influence each other during the process only the rotational speed and the feed rate will be varied, as these parameters are known to greatly influence the heat input during the welding process. The rationale behind the methodology used in analysing and characterizing the welded Samples are as follows.

Micro hardness testing: This is an important mechanical characteristic that governs the wear resistance of materials. Micro-hardness profiling in this research was used to characterize the formation of precipitates in the weld. It was also used to characterize the hardness of the different weld zones.

Mechanical testing - This test is to measure properties such as hardness, tensile strength, ductility.

2.3 Material details

AA 2024 Aluminium Alloy: Is an aluminium alloy, with copper as the primary alloying elements, It is used in applications requiring high strength to weight ratio, as well as good fatigue resistance. It is weldable only through friction welding, and has average machinability. Due to poor corrosion resistance, it is often clad with aluminium or Al-1Zn for protection, although this may reduce the fatigue strength. In older systems of terminology, this alloy was named 24ST. 2024 is commonly extruded, and also available in AL clad sheet and plate forms. It is not commonly forged (the related 2014 aluminium alloy is, though)

Chemical Composition of AA 2024

Table 2.1: Chemical composition of al 2024

Elements	Content % of Weight
Si	0.50
Fe	0.50
Cu	3.8-4.9
Mn	0.30-0.9
Mg	1.2-1.8
Cr	0.10
Zn	0.25
Ti	0.15
Others-Each	0.05
Others Total	0.15
Al	Remainder

Mechanical properties of AA 2024

Table 2.2: Mechanical properties of al 2024

Alloy-Temper	Tensile Strength(Mpa)	Yield Strength(Mpa)	Elongation (%)
2024-O	117	76	18
2024-T3	483	345	16
2024-T4	414	350	20

Applications

Due to its high strength and fatigue resistance, AA 2024 is widely used in aircraft, especially wing and fuselage structures under tension. Additionally, since the material is susceptible to thermal shock, 2024 is used in qualification of liquid penetrant tests outside of normal temperature ranges.

AA 6061 Aluminum Alloy: 6061 is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S", it was developed in 1935 [2]. It has good mechanical properties, exhibits good weldability, and is very commonly extruded (second in popularity only to 6063) [3]. It is one of the most common alloys of aluminium for general-purpose use. It is commonly available in pre-tempered grades such as 6061-O (annealed), tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).

Mechanical properties of AA 6061

Table 4.3: Mechanical properties of al 6061

Alloy-Temper	Tensile Strength(mpa)	Yield Strength(mpa)	Elongation (%)
6061-O	124	55	25
6061-T4	241	145	22
6061-T6	310	276	12

Chemical composition of AA 6061

Table 4.4: Chemical composition of al 6061

Elements	Content % of weight
Si	0.40-.8
Fe	0.7
Cu	0.15-0.4
Mn	0.15
Mg	0.8-1.2
Cr	0.04-0.35
Zn	0.25
Ti	0.15
Others-Each	0.05
Others Total	0.15
Al	Remainder

Basic properties of AA 6061

Aluminum alloy of 6061 the Density (ρ) = 2.70 g/cm³, Melting temperature (T_m) = 585 °C, Thermal conductivity (k) = 151–202 W/(m·K), Specific heat capacity (c) = 897 J/(kg·K), Young's modulus (E) = 68.9 GPa, Poisson's ratio (ν) = 0.33

Applications of AA 6061

Aircraft and aerospace components, Marine fittings, Transport, Bicycle frames, Camera lenses, Driveshaft, Electrical fittings and connectors, Valves & Couplings

Tool material

There are several types of tool materials used in friction stir welding are given below Copper carbide, Tungsten carbide, Vanadium carbide, High speed steel. High alloy, High speed carbon, Boron nitride, Poly carbon boron nitride, High carbon high chromium steel (D1, D2, D3, D4, D5, D7)

High Carbon, High Chromium (HCHCR)

The high-carbon, high-chromium tool steels are the most highly alloyed steels.

There are five standard AISI (UNS). Types of these steels:

- D2 (T30402),
- D3 (T30403),
- D4 (T30404),
- D5 (T30405) and D7 (T30407).
- D1 and D6 are no longer in common use.

D-type tool steels contain between 10% and 18% chromium. These steels retain their hardness up to a temperature of 425 °C (797 °F). Common applications for these grade of tool steel is forging dies, die-casting die blocks, and drawing dies. Due to high chromium content, certain D-grade tool steel grades are often considered stainless or semi-stainless tool steels. However their corrosion resistance was very limited due to the precipitation of major amount of chromium and carbon as carbides.

Die steel (D2) Properties

D2 Die steel is an air hardening, high-carbon, high-chromium tool steel. It has high wear and abrasion resistant properties. It is heat treatable and will offer a hardness in the range 55-62 HRC, and is machinable in the annealed condition. D2 steel shows little distortion on correct hardening. D2 steel's high chromium content gives it mild corrosion resisting properties in the hardened condition.

Typical chemical composition of AISI D2 Steel

Table 4.5: Chemical composition of AISI D2 Steel

C	SI	Cr	Mo	V
1.50%	0.30%	12.00%	0.80%	0.90%

Proposed work

Typical applications for D2 Steels

Stamping or Forming Dies, Punches, Forming Rolls, Knives, slitters, shear blades, Tools, Scrap choppers, Tyre shredders.

Experimental Setup

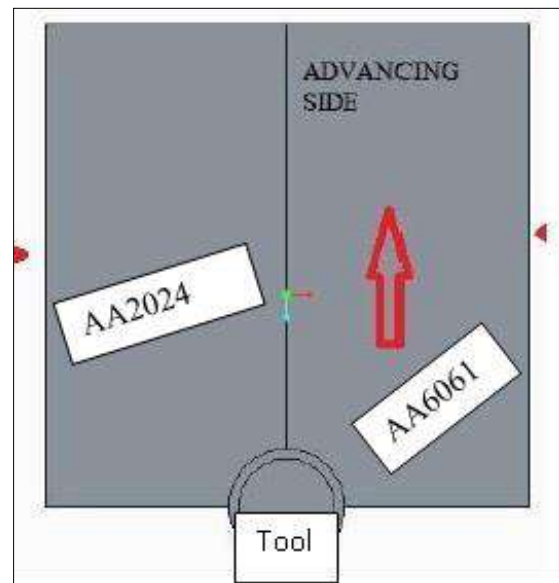


Fig 3.1: Welding setup

3.1 Detail of experiment

The experiment is to be carried out in joining of two dissimilar material like aluminum alloy 2024 and aluminum alloy 6061 by used the friction stir welding with various pin profiles.

The dissimilar material dimensions are 50mm×100mm×6mm of each plate and for their experimental work, tool geometry selected in straight circular, and octagon pin profile are shown in (Fig 3.2 & 3.3), where tool is made up of high carbon high chromium steel (HC-HCR).

These experiment is to be carried out by modified vertical milling machine and friction stir welding machine, for the trail run had been held on modified milling machine, has been used the following parameters are consider to below mentioned.

Welding parameters

Table 3.1: Welding parameters for circular pin

Parameters	Values
Shoulder diameter	24mm
Pin diameter	6mm
Shoulder length	15mm
Pin length	5.6mm
Shape of pin	Circular
Travel speed	900-1800Rpm
Feed	10-40mm/min

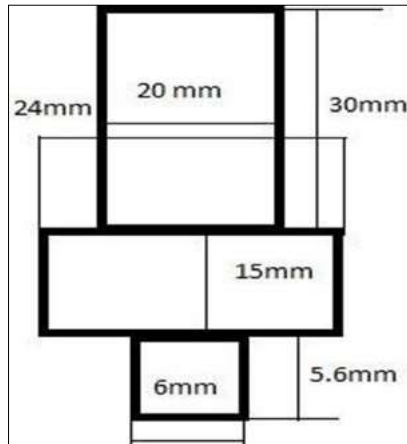


Fig 3.2: cylindrical probe

Table 3.2: welding parameters for octagon pin

Parameters	Values
Shoulder diameter	24 mm
Pin diameter	6 mm
Shoulder length	15 mm
Pin length	5.8 mm
Shape of pin	Octagon
Travel speed	900-1800 rpm
Feed	10-40 mm/min

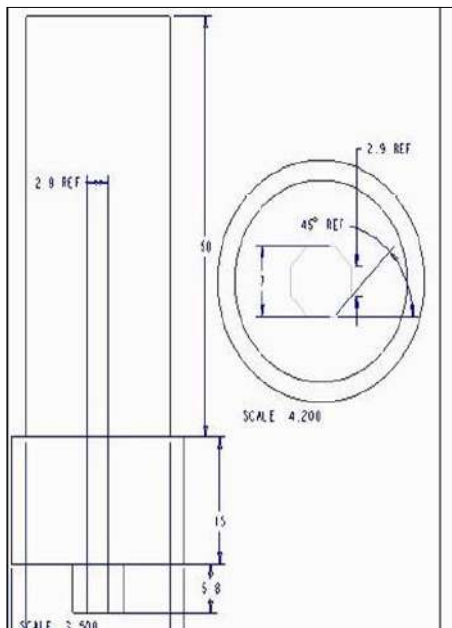


Fig 3.3: octagon pin probe



Fig 3.4: circular pin profile tool



Fig 3.5: octagon profile tool



Fig 3.4: 1 octagon pin

Fabricated tool material

3.2 Machinery details

Details of retro fixed vertical milling machine

Table 3.5: Detail and Parameter of Vertical Machine

Details	Range
Power operated Longitudinal Traverse	560 mm
Power operated Cross Traverse	250 mm
Vertical Traverse Manual	160 mm
No. of Speeds	12
Speed range	45, 63, 96, 125, 180, 250, 355, 500, 710, 1000, 1400, 2000.
Feed range in mm/min	20, 30, 35, 80, 125, 200, 315, 500, 800



Fig 3.6: Retro Fixed Vertical Milling Machine

Trail experiment

Table 5.4: Trail experiment parameters

Pin Profiles	Rotational Speed (Rpm)			Transvers Speed Mm/min	Depth (mm)
	1	2	3		
Cylindrical	500	710	1000	20	5.6
Octagon	500	710	1000	20	5.6

Trail weld plate results by used octagon pin

The trial welding was conducted on AA2024 and AA6061 with octagonal pin with parameters 500 rpm with feed of 20 mm / min and depth was given as 5.6 mm. the result obtained was a good weld with a small crack due to excessive temperature distribution and pilot hole was formed at the end.



Fig 3.7: Weld at 500 rpm, feed of 20 mm/min and depth is 5.6 mm
The trial welding was conducted on AA2024 and AA6061 with octagonal pin with parameters 700 rpm with feed of 20 mm / min and depth was given as 5.6 mm. the result obtained was a onion rings with a small crack due to excessive temperature distribution and pilot hole was formed at the end.

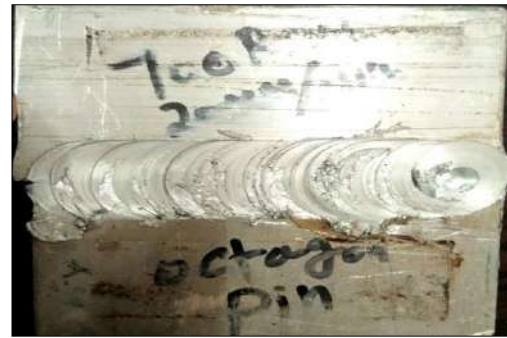


Fig 3.8: Weld at 710 rpm, feed 20 mm/min and depth 5.6 mm

The trial welding was conducted on AA2024 and AA6061 with octagonal pin with parameters 1000 rpm with feed of 20 mm / min and depth was given as 5.6 mm. the result obtained was a little bit onion rings are formed and good weld with a small crack occurred at started of weld due to excessive temperature distribution and pilot hole was formed at the end. After the test pin profile was changed to circular because due to metal formation of pin.



Fig 3.8: Weld at 1000 rpm, feed 20 mm/min, and depth 5.6 mm

After the conducted the experiment probe shape has been changed of octagon to circular due to metal formation in probe. It occurred after conducting trail welding at different rotational speed 500 rpm, 710 rpm, and 1000 rpm respectively.



Fig 3.9: after weld of pin at 710 rpm

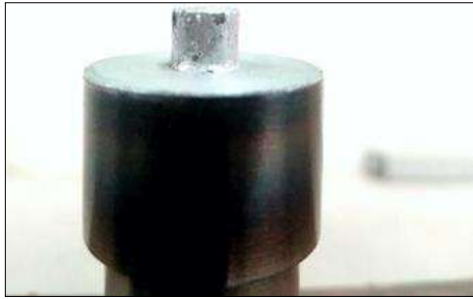


Fig 3.10: after weld of pin at 1000 rpm

4. Conclusion

Result

In this thesis, Friction Stir Welding of AA2024 and AA6061 was welded using an octagon probe tool and weld was produced. The tool was designed according to plate thickness with the pin diameter as 6.4 mm. The real time welding was conducted at retro fixed welding machine at TCE machine shop and where good weld was produced with pilot hole drill, visual defects of onion rings and little bit crack are obtained at various speed. The optimized weld parameter obtained was:

Rotation speed (rpm)	Traverse speed (mm/min)	Depth (mm)
500	20	5.7
700	20	5.7
1000	20	5.7



Fig 4.1: Optimized Welding Parameters

From this observation the good weld is been identified rotational speed 500 rpm and 1000 rpm are respectively and both transvers speed 20 mm/min and depth 5.7 mm are respectively. The visual defects are given below fig 4.1, 4.2 and 4.3 respectively



Fig 4.1: obtained defect at starting stage due to temperature distribution at 500 rpm, transvers speed 20 mm/min



Fig 4.2: Defect weld due to improper weld obtained at 700 rpm transvers speed 20 mm/mm



Fig 4.3: Good weld with crack obtained at starting stage due to temperature distribution in 1000 rpm rotational speed, transvers speed 20 mm/min

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