

# An Assessment of Non Consumable Welded Joint-Friction Stir Spot Welding

C. Labesh Kumar, G. Bharathiraja



**Abstract:** Friction stir spot welding (FSSW) is a pressure welding process where the workpieces are operated below their melting points. FSSW is one of the processes derived from Friction Stir Welding (FSW) Technology. Friction stir welding was invented by The Welding Institute (TWI) in 1991 and proven experimentally. FSSW is found to be environment friendly and a very efficient process. This process is rapidly growing and is replacing the resistance spot welding. FSSW have various applications which include industries like automobile, aerospace, ship building, construction and electrical. FSSW has been successfully used to join several materials used in the above mentioned industries. In this review, FSSW studies are briefly summarised in terms different parameters for joining processes.

**Keywords:** FSSW, FSW, construction and electrical.

## I. INTRODUCTION

Friction Stir Welding (FSW) process was invented and experimentally proven by The Welding Institute (TWI) in 1991 for joining Aluminium alloys [1]. Friction Stir Spot Welding (FSSW) is a variant of the FSW which is found to

be environmental friendly and an efficient process. It is majorly used for difficult to weld sheets for lap joints [3]. In this process two work pieces are joined using a non-consumable tool which rotates at a certain speed. The rotating tool is plunged into the workpieces for a predetermined time which is referred as dwell time. After dwell time the tool is retracted from the workpieces leave the Friction stir spot weld. During Friction Stir Spot Welding (FSSW), the plunge depth and dwell time determines the heat generation, amount of material plasticized and mechanical properties of the joint formed [2].

## FSSW PROCESS

The process mainly consists of three segments plunging, stirring and retracting or drawing out. The tool is driven by a motor attached to the spindle. The tool is rotated at speed range of 1000rpm to 2000rpm. The tool is brought in contact with the workpiece, as the tool is in contact with the tool due to the friction between the tool and workpiece heat is generated.

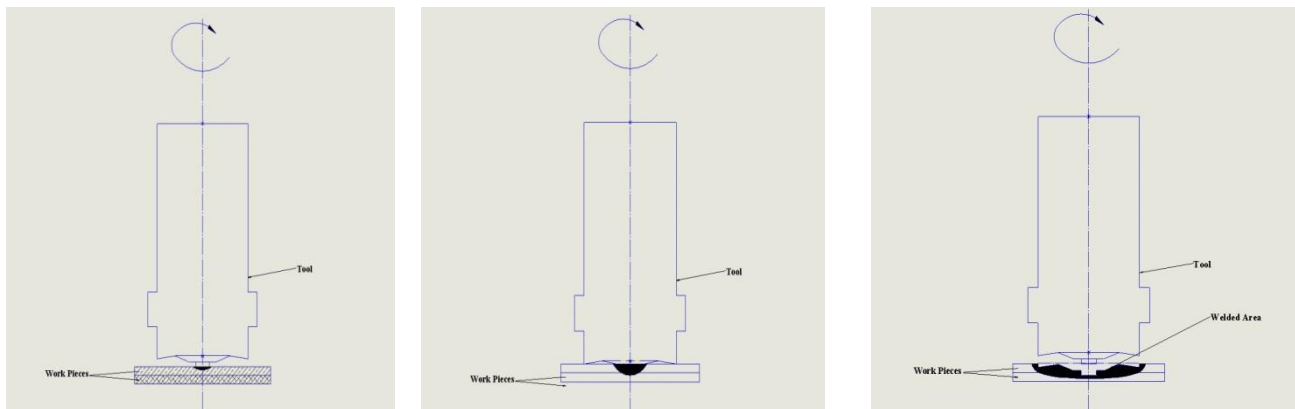


Fig-1: Plunging, Stirring, Drawing out

Due to the heat generated the workpiece material is plasticized (softened) and load is applied on the tool spindle which results in the penetration of the work piece by the tool. This process of penetration of the rotating tool into the workpiece is called plunging.

The rotating tool then stirs the softened metal till it is in contact with the workpiece, this called stirring. After a while the tool is retracted from the workpiece leaving the two plates (workpiece) welded.

This process is becoming so efficient that it is replacing the resistance spot welding enhancing the strength, efficient and properties of the joints. The Friction Stir Spot Welding has a wide range of applications in the automobile, aerospace, electrical and construction sectors.

## 1. PROCESS PARAMETERS

There are three main process parameters which are tool rotational speed, plunge depth and dwell time.

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## 1.1. Tool rotational speed

The tool rotational speed plays vital role in the process. The profiled tool rotates at a certain speed at around 1000 rpm to 2000 rpm [1].

When the rotating tool come in contact with the work piece or the spot where the joint needs to be formed, due to the friction developed between the tool and the workpiece the metal gets plasticized so that the tool gets penetrated into the workpiece to form the weld joint. The continuous rotation of the tool, also known as stirring, resists the solidifying of the metal and keeps it in a semi-solid state. This stirring contributes to the formation of the weld joint.

## 1.2. Plunge Depth

The plunge depth is the depth of penetration of the tool into the workpiece to an extent such that the weld can be done. Usually for spot welding we use two plates, thus for FSSW also we use two plates. As the rotating tool is plunged into the workpiece the depth should be in such a length that the tool should penetrate till the half of the depth of the second plate.

## 1.3. Dwell Time

The dwell time is the total time duration for which the tool is in contact with the work piece during plugging, stirring and retracting. Dwell time plays a major role in deciding the joint properties followed by rotational speed and plunge depth [10].

## II. TOOL NOMENCLATURE

The non-consumable rotating tool is designed on the basis of the materials to be joined. The basic tool for this process has a shoulder on which a tapered pin is mounted. There are many different tool geometries proposed square profiled, triangle profiled, cylinder profile, etc. [11].

### 2.1. Pin Length

The pin length determines the plunge depth which results in the weld joint [8]. The welding with tools with shorter pin length improves the forging and welding of Al onto the steel because of the increase of thermomechanical effect of the shoulder onto the joint interface. The effective bonding length is increased when welded with short pin length [8].

### 2.2. Pin Profile and tool shoulder

The rotating tool consisting of a shoulder and pin or probe. The shoulder applies a downward pressure to the work piece surface, generates heat through the friction and leads to plasticization of materials in the vicinity of pin. The pin profile and tool shoulder contributes significantly to the weld joint. The better production output depends on the tool pin profiles [14].

## III. EFFECT OF PROCESS PARAMETERS ON THE JOINT

### 3.1. Tool Rotational Speed

The tool rotational speed should be high enough so that the workpiece material becomes plasticized due to the friction between the rotating tool and workpiece. The tool speed is one of the key components of the FSSW process.

The process time depends on the tool speed, as the friction between the tool and workpiece depends on the rotational Speed. Hence, higher the rotational speed, better the friction.

### 3.2. Plunge Depth

In FSSW, the tool should plunge the into the workpiece consisting of two plates in a manner such that it should penetrate the first plate and then penetrate till the half of the thickness of the second plate. Excess or low plunge depth may fail the joint. Hence the plunge depth should be optimum.

### 3.3. Dwell Time

The dwell time is a parameter which depends on the above two parameters. Dwell time is the total time for which the tool and the workpiece are in contact with each other during the formation of the weld joint. These parameters will influence the strength of welded joint and also the nature of surface produced.

## IV. NOMENCLATURE OF THE WELDED REGIONS

To know about the welded joint it is very effective to give a specific naming to joint section the weld section is classified to three important zones.

The Stir Zone (SZ)

The Heat Affected Zone (HAZ) and

The Thermomechanical Affected Zone (TMAZ)

### 4.1. The Stir Zone

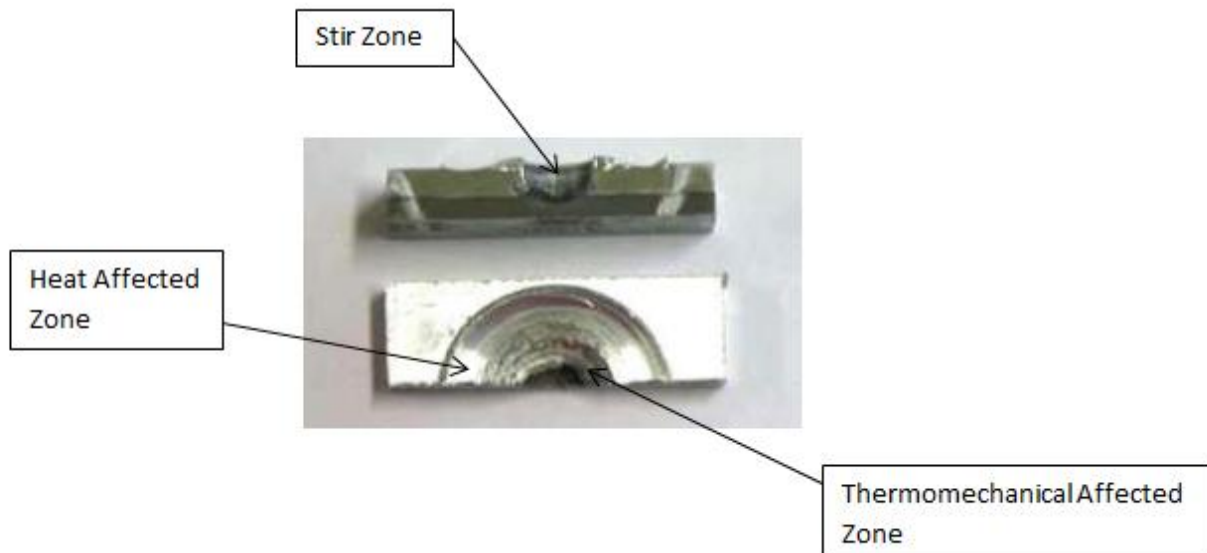
The tool with pin head rotates at a given RPM on the welded region which causes the material to recrystallize on the work piece the zone is termed as stir zone. The material flow in this region has different grain structure when compared to the original work piece grain structure and they are smaller in size this zone is considered to be important accept in the welding joint.

### 4.2. The Heat Affected Zone

Due to effect of stir this zone is developed behind the stir zone and will undergo a thermal modification which in turn affects the micro structure and mechanical properties of the welding joint.

### 4.3. The Thermomechanical Affected Zone

This zone under goes plasticity future it will help in the formation of joint. In some materials, plastic strains can be obtained without recrystallization in this area.



### V. VIEWS OF DIFFERENT LITERATURE ON FSSW

It is important to understand the tool structure and weld zone region to obtain a suitable weld joint. The process parameters also play a vital role to form a good joint. There are many studies suggested that a tool with pin profile will generate good amount of heat which makes the joint possible for steel materials.

Investigation of fatigue fracture mechanism of friction stir spot welded 300MPa class low carbon steel sheets used as a general automobile steels. Fatigue strength of the material is observed or tested at low and high force amplitudes using 3-D observation method. AISI-1012 sheet low carbon steel of 8mm thick is used. Fatigue tests were conducted by using servo hydraulic testing machine in a cyclic loading. Crack initiation occurs as a boundary between the welding interface zone and non-interface zone or stir tip regarding less of amplitude level located in the heat affected zone [4].

The metals used in this paper are Al5083 and C10100 which are alloys of aluminium and copper. The effect of piercing and puncturing of the tool on the top layer (aluminium alloy) and on the bottom layer (copper alloy) were analysed by varying the predominant Friction Stir Spot Welding (FSSW) process parameters like tool rotational speed, dwell time and plunge depth. A vertical heavy type CNC machine was used for the experiment. The tool used was in cylindrical shape with pin in cylindrical shape with flat shoulders (i.e. without tapered angles) and was made of H13 tool steel. The difference in shoulder and pin interaction is seen with the type of surface deformations and the pattern of mixing material at the weld region [6].

To study the effect of the pin length of the welding tool and its penetration depth during Friction Stir Spot Welding tool of overlap joints of Al alloys AA6063 with galvanised low carbon steel. Every weld spot was done with penetration rate of 19mm/min and dwell time of 1second. Three different tools were fabricated with different pin lengths and all of them were smoothly tapered. For the macrostructures the specimens were etched with Keller's reagent and observed under light microscope. The welding with tools with shorter pin length improves the forging and welding of

Al onto the steel because of the increase of thermomechanical effect of the shoulder onto the joint interface. The effective bonding length is increased when welded with short pin length. When the distance between the lower point of the shoulder and the interface is high (low tool penetration depth), the failure is interfacial with low failure load. When distance between the lower point of the shoulder and the interface (IH) is reduced, the failure load is increased. Optimum balance between effective joint length and IH improves the mechanical properties [9].

Process parameters play a vital role in Friction Stir Spot Welding (FSSW) as they constitute to the joint strength. Design of experiments was used to conduct the experiments for exploring the interdependence of the [process parameters. Dwell time plays a major role in deciding the joint properties followed by rotational speed and plunge depth. By numerical and graphical optimization techniques, optimum process parameters are identified for maximum lap shear strength. Response surface methodology was used to optimize the process parameters in this paper. The order of influence of the process parameters is Dwell time, tool rotational speed and plunge depth. [10].

The effect of shoulder surface and pin profiles during Friction Stir Spot Welding of sandwich sheet has been attempted with different tool geometries. Lap shear tests are performed to evaluate the mechanical performance. During lap shear test, the tool with square pin produced stronger joints. The square pin tool produces joints with moderate hook distance, hook width and hook height and larger bond area which result in stronger joints. The joints made from tri-metallic sheet perform better than sandwich sheet joints. . The joints made with square pin can withstand a fracture load of 1.4 kN in case of sandwich sheet, and about 2.8 kN in case of tri-metallic sheet. In both the cases, the FSSW tool with threaded pin (thr tool) produced a weaker joint. About 65-75% load bearing ability is reduced when the pin profiles are changed. The joint strength depends on the hook's morphology and bond area [11].



# An Assessment of Non Consumable Welded Joint- Friction Stir Spot Welding

Friction stir forming (FSF) refers the process variant of friction stir welding (FSW) where a joint is achieved through the creation of mechanical interlocking between two constituents by plasticizing one material through the use of the FSW process and in turn forcing said material to flow into the second material. a method of quantifying the plasticity of flowing material during the FSF process is needed to increase the understanding of material flow within this process. A method is proposed in which a capillary hole is drilled into a backing plate used for FSW, and the material is extruded through the capillary during processing. A method of determining the effective viscosity of plasticized material produced by FSW was developed from the basic principles of a capillary rheometer [12].

The effect of the tool penetration depth during welding and the relative position of the materials used in the super imposed joints. The sample of AA5052-AA6063 sheets welded. Macrostructural and dimension characterization, micro hardness profiles and Peel tests (PT) were done for different conditions. The fracture loads in PT increased with the tool penetration depth for both material positions, being higher when AA6063 was the upper material. The different aluminium alloys are AA5052 and AA6063. the material flow rate out of the spot increases with tool penetration depth. Friction stir spot welds on dissimilar (materials and thicknesses) aluminium alloys were produced with different Tool Penetration Depth and sheets relative position. The joints obtained were sound and defects-free for all the analysed welding conditions. To evaluate the thermomechanical effect of tool shoulder on the interface for dissimilar thicknesses IH is a more effective parameter [13].

Friction stir welding (FSW) is a solid state joining process which uses a rotating tool consisting of a shoulder and a pin/probe. The shoulder applies a downward pressure to the work piece surface, generates heat through the friction and leads to plasticization of materials in the vicinity of pin. This paper investigates a model based approach in knowing the effect of various tool pin profiles on temperature, stir zone and power consumed for welding. A three-dimensional (3-D) model is developed in finite element (FE) which helps in a better tool design. In this paper six tools with different geometries are designed, fabricated and simulated. The results are obtained best when a square pinned frustum tool is used [14].

A finite element (FE) thermal model for joining two similar metal alloys and two dissimilar metal alloys using Friction Stir Spot Welding are developed for two tool geometries (i.e. one with flat face and the other with fluted surface). The FE model was applied to study two important microstructural changes in FSSW of aluminium. (i) The thermal histories were combined with a microstructural model for the formation of intermetallic compounds at the interface in an Al 6111-steel weld. The strong sensitivity of the microstructural results to uncertainty in the temperature history was demonstrated. (ii) The evolution of post-weld hardness of FSSW Al 6111 was studied which was compared with an ultrasonic welding joint. This obtained the

result that, the relationship was characteristic of the alloy, and was independent of the welding process [15].

Material characterization of dissimilar friction stir spot welded Aluminium and Copper was evaluated. The process parameters rotational speed and transverse speeds are varied and results are obtained. The spot welds microstructures are characterized using optical electron microscope (OEM) and scanning electron microscopy technique (SEM) is obtained by observing the evolution of the microstructure across the weld's cross-section. The lap shear tests are also done on the spot welded specimen joints. From the obtained result we can say that the change in the feed rate didn't have significant effect on the weld integrity (joint). Hence we can conclude that welding of metals and alloys using Friction stir spot welding is appropriate and can be used in many industrial applications [16].

Friction welding is becoming an alternative for rivets, electric resistance welding and offer substantial advantages like energy consumption, environmental protection and mechanical properties of the weld. In this paper the analysis of the plunge and dwell phase of Friction Stir Welding (FSW) are done using a three dimensional finite element modelling. In this paper four tools with different configurations (geometries) are designed and simulated by varying the process parameters. The tools with square and tringle profiled pin helped in increasing the process temperature and widening the weld nugget with less power consumption when compared to the other tool geometries. The Coupled Eulerian-Lagrangian (CEL) method exhibits the potential to predict the defect for obtaining the optimum process parameters [17].

## VI. RESULT AND DISCUSSIONS

Processes parameters have a vital role to play in judging the weld strength and quality. The tool has to with stand high heat and vertical force when the process is carried out on the machine. The optimum value which has been found out in all the above studies has given a challenging environment for joining of dissimilar metals especially steels. The size of welding joint completely depends on the size of the shoulder pin as it penetrates the work pieces. The weld shows a good structure after it has undergone nondestructive test with through joining between to weld mates. Dwell time play a vital role in the joining process as it deals with the strength of the welded joint. A special fixture should be developed for the proper aliment of the weld mates and at required spot.

**Table 1: weld strength results**

RPM	Thickness (mm)	Dwell Time (s)	Tensile Strength (kN)
1200	2x2	20	5.90
1200	2x3	23	5.20
1200	2x4	26	5.00
1500	2x2	23	6.50
1500	2x3	26	5.98
1500	2x4	20	5.50
1800	2x2	26	6.70
1800	2x3	20	5.70
1800	2x4	23	5.90

## VII. CONCLUSION

Significant research and development on FSSW has been carried throughout the world and this process proves to be an option for many automobile and aerospace industries. A deep literature review has been conducted on this for joining of similar and dissimilar metals. It is a low weight and high strength joining process where the non-consumable tool makes the joint possible by string on the metals with high RPM. As the tool is made of hard material and high melting temperature material it will be a good challenge to join different steels with other alloying materials which results in strong joint with less tool wear and high strength. This process will be proven effectively and economically when compared to other welding processes.

## REFERENCES

- Mukuna P. Mubiayi and Esther T. Akinlabi, "An Overview on Friction Stir Spot Welding of Dissimilar Materials", DOI: 10.1007/978-94-017-7236-5\_38.
- Mukuna P. Mubiayi, and Esther T. Akinlabi, "Friction Stir Spot Welding of Dissimilar Materials: An Overview", Proceedings of the World Congress on Engineering and Computer Science 2014 Vol II WCECS 2014, 22-24 October, 2014, San Francisco, USA.
- G.K Padhy, C.S Wu, S.Gao, "Friction stir based welding and processing Technologies processes, parameters, Microstructures and applications: A review", Journal of Material Sci. and Technol. 34 (2018) 1-38.
- S. Joy-A-Ka, Y. Ogawa, A. Sugeta, Y.F. Sun and H. Fujii, "Fatigue Fracture Mechanism on Friction Stir Spot Welded Joints Using 300 MPa-Class Automobile Steel Sheets under Constant and Variable Force Amplitude", Procedia Materials Science 3 (2014) 537-543.
- F.C. Liu, Y. Hovanski, M.P. Miles, C.D. Sorensen, T.W. Nelson, "A review of friction stir welding of steels: Tool, material flow, microstructure, and properties", Journal of Material Sci. and Technol. 34 (2018) 39-57.
- Gianluca Buffa, Pierluigi Fanelli, Livan Fratini, Francesco Vivio, "Influence of joint geometry on micro and macro mechanical properties of friction stir spot welded joints", Procedia Engineering 81 (2014) 2086 - 2091.
- S. Siddharth, T. Senthilkumar, "Study of tool penetration behaviour in Dissimilar Al5083/C10100 friction stir spot welds", Procedia Engineering 173 (2017) 1439 - 1446.
- Joaquin M. Piccini, Herman G. Svoboda, "Effect of pin length on Friction Stir Spot Welding (FSSW) of dissimilar Aluminum-Steel joints", Procedia Materials Sci. 9 (2015) 504-513.
- M. Haghshenas, A.P. Gerlich, "Joining of automotive sheet materials by friction-based welding methods: A review", Engineering Sci. and Technol. 21 (2018) 130-148.
- A.K. Lakshminarayanan, V.E. Annamalai, K. Elangovan, "Identification of Friction stir spot welding process parameters controlling the properties of low carbon automotive steel joints", J Mater. Res. Technol. 2015; 4 (3): 262-272.
- Karn Kumar Ravi, R. Ramesh Narayanan, Pritam K. Rana, "Friction Stir Spot Welding of Al6082-T6/HDPE/Al6082-T6/HDPE/Al6082-T6 sandwich sheets: hook formation and lap shear test performance", J Mater. Res. Technol. 2018.
- Daniel J. Franke, Justin D. Morrow, Michael R. Zinn, Neil A. Duffie, and Frank E. Pfefferkorn, "Experimental Determination of the Effective Viscosity of Plasticized Aluminum Alloy 6061-T6 during Friction Stir Welding", Procedia Manufacturing 10 (2017) 218-231.
- Joaquin M. Piccini, Hernán G. Svoboda, "Effect of the tool penetration depth in Friction Stir Spot Welding (FSSW) of dissimilar aluminum alloys", Procedia Materials Science 8 (2015) 868-877.
- Vinayak Malik, Sanjeev N K, H. Suresh Hebbar, Satish V. Kailas, "Investigations on the Effect of Various Tool Pin Profiles in Friction Stir Welding Using Finite Element Simulations ", Procedia Engineering 97 (2014) 1060-1068.
- P. Jedrasiak, H.R. Shercliff, A. Reilly, G.J. McShane, Y.C. Chen, L. Wang, J. Robson, and P. Prangnell, "Thermal Modeling of Al-Al and Al-Steel Friction Stir Spot Welding", JMEPEG DOI: 10.1007/s11665-016-2225-y 1059-9495.
- K. O Sanusi and E. T. Akinlabi, "Material Characterization of Dissimilar Friction Stir Spot Welded Aluminium and Copper Alloy", 2017 IOP Conf. Ser.: Mater. Sci. Eng. 225 012057.
- Vinayak Malik, Sanjeev N.K, H. Suresh Hebbar, Satish V. Kailas, "Time Efficient Simulations of Plunge and Dwell Phase of FSW and its Significance in FSSW", Procedia Materials Sci. 5 (2014) 630-639.
- X.W. Yang, I. T. Fu, I. and W.Y. Li, "Friction Stir Spot Welding: A Review on Joint Macro and Microstructure, Property, and Process Modelling", Hindawi Publishing Corporation, Volume 2014, Article ID 697170, 11 pages, web link : <http://dx.doi.org/10.1155/2014/697170>.
- Labesh Kumar, C., Jayakumar, V., Bharathiraja, G. "Optimization of welding parameters for friction stir spot welding of AA6062 with similar and dissimilar thicknesses" Materials Today: Proceedings Volume 19, 2019, Pages 251-255. ISSN: 22147853 DOI: 10.1016/j.matpr.2019.07.204.

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