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Friction stir spot welding – A critical review

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ABSTRACT

Friction stir spot welding as a derivative of friction stir welding has been developed for joining body structures. In Friction stir Spot the rotating tool is plunged through the upper sheet into the lower sheet to a predetermined depth, with the shoulder in close contact with the upper sheet. The tool is then held into the metal sheets for a short duration before its retraction. A small amount of material is squeezed out of the shoulder to form a circular protrusion on the upper sheet. A round indentation called weld keyhole remains in the weld after the pin retraction. Due to an overlap welding configuration, a friction stir spot weld shows a distinct macrostructure. In this paper Friction stir, spot welding is reviewed and discussed.

Keywords: *Welding, Materials, Tool, Microstructure, SEM.*

1. INTRODUCTION

Material flow during friction stir spot welding

Material flow during friction stir spot welding [1] is investigated using tracer material technique. Three distinct regions are developed in a weld after the rotating shoulder comes in close contact with the upper sheet. They are called flow transition zone, stir zone, and torsion zone which are evolved due to the combination of rotational, horizontal and vertical motions of the plasticized material. An incorporation of the upper and lower sheet materials takes place in the flow transition zone, and the intermingled materials flowing from the flow transition zone contribute primarily to the formation of the stir zone. Before the shoulder contacts the upper sheet, the pin mainly extrudes the material downwards, causing the adjoining lower sheet material to move upwards into the upper sheet. After the rotating shoulder comes in close contact with the upper sheet, three distinct regions are developed in a weld. They are the flow transition zone immediately underneath the tool shoulder, the stir zone around the pin, and the torsion zone underneath the pin which are evolved due to the combination of rotational, horizontal and vertical motions of the plasticized material. The material release from the pin surface through an outward-spinning motion provides an intrinsic driving force for the downward spiral motion of the plasticized material along the pin. The cooperation of three material transport processes that are (1) the upward motion of the lower sheet material and the incorporation of the upper and lower sheet materials, (2) the downward spiral motion of the incorporated materials along the pin, and (3) the release of the incorporated materials from the pin, contributes to forming the stir zone. As the stir zone expands, the material immediately outside the stir zone could flow towards the pin by following the stir zone extremity and be forced directly into the stir zone. In the torsion zone, the material underneath the pin moves downwards in a swirling motion due to the effect of high-pressure torsion.

Characteristics of friction stir spot welding of Zr-based bulk metallic glass sheets.

The friction stir spot welding of Zr-based BMG sheets [2] has been investigated using an apparatus which was devised with a CNC milling machine to give a precise control of the friction time and the plunge depth. The variation of vertical load pressing the sheet specimens and the temperature history during friction stirring were measured which are closely related to the deformation behavior of BMG materials at the super cooled liquid region. A characteristic behavior during Friction stir spot welding of BMG sheets was found. Influences of the plunge speed and plunge depth on the characteristic features of FSSW of BMG sheets were investigated. The micrographic observation and the tensile shear test were carried out to characterize the FSSW of BMG sheets.

Influence of tool path in friction stir spot welding of aluminum alloys

Friction stir spot welding has been proposed as an effective technology to spot weld the so-called difficult to be welded metal alloys.[3]. A tool path is given after the sinking phase nearby the initial penetration site; in this way, a larger welding spot is obtained and more material is involved in the bonding process. The process mechanics of such modified FSSW process is highlighted and the joint strength undergoing tensile tests is considered at the varying both of the assigned tool path and of a few process parameters. Macro- and micro-analyses are made in order to analyze the local material microstructure evolution. It is found that improved performances, with respect to the traditional FSSW process, are obtained for all the considered case studies.

Friction stir spot welding of hot-stamped boron steel

Hot-stamped boron steel was successfully joined by friction stir spot welding using polycrystalline cubic boron nitride tooling.[4] The resulting microstructure, micro hardness, and mechanical properties are reported, including a brief look into failure mechanisms. Relationships between the unique mechanical mixing, phase transformations and failure initiation sites associated with joining martensitic steels are characterized. Tensile-shear fatigue tests were performed using lap-shear specimens at a stress ratio $R = 0.1$ in order to figure out fatigue behavior of dissimilar welds. The tensile-shear strength of the dissimilar welds was higher than that of the A6061 similar ones. Furthermore, the dissimilar welds exhibited nearly the same fatigue strengths as the A6061 similar ones, indicating that FSSW by a scroll tool was an effective technique for joining aluminum to the steel sheet.

Feasibility of friction spot welding in PMMA

In this work, the authors have described the feasibility of friction spot welding of thermoplastics plates. [5] Preliminary results have shown that the weld strength is comparable to other available welding techniques while joining times are equal or shorter. Light optical microscopy and Vickers microhardness measurements showed the presence of a heat affected zone and a thin, consolidated stir zone, where physical–chemical transformations related to thermo-mechanical processing led to changes in local mechanical strength. The work has demonstrated for the first time that the welding of thermoplastic materials by friction spot welding is feasible. Structure properties relations in spot friction welded (also known as friction stir spot welded) 6111 aluminum.

Fatigue lives of friction stir spot welds in aluminum 6061-T6 sheets

The fatigue lives of friction stir spot welds in aluminum 6061-T6 lap-shear specimens under cyclic loading conditions are investigated in this paper.[6] The paths of fatigue cracks near friction stir spot welds in lap-shear specimens are first examined. The experimental observations suggest that under cyclic loading conditions, the fatigue crack is initiated near the possible original notch tip in the stir zone and propagates along the circumference of the nugget, then through the sheet thickness and finally grows in the width direction to cause a final fracture. A fatigue cracks growth model based on the Paris law for crack propagation and the local stress intensity factors for kinked cracks is then adopted to predict the fatigue lives of friction stir spot welds.

A newly developed tool without a probe for friction stir spot welding.

A newly developed tool for friction stir spot welding (FSSW)has been proposed, which has no probe, but a scroll groove on its shoulder surface (scroll tool).[7] By use of this tool, FSSW has performed on aluminum alloy 6061-T4 sheets and the potential of the tool was discussed in terms of weld structure and static strength of welds. The experimental observations showed that the scroll tool had the comparable or superior performance to a conventional probe tool. It was confirmed that sound welding could be achieved without a probe hole, in which the scroll groove played significant roles in the stirring of the material and the shoulder plunge depth was the important processing variable. The maximum tensile-shear strength of the welds made by the scroll tool was found to be 4.6kN that was higher than that of the welds made by the probe tool. Two different fracture modes, shear fracture, and plug fracture were observed depending on processing condition.

Mechanical characterization of friction stir spot micro welds

Microstructures and failure mechanisms of friction stir spot micro welds in 3mm thin sheet of aluminum 1050 alloy were investigated.[8] As an alternative to conventional soldering and welding in joining thin metals for electronic, medical and micro devices, friction stir welding may be utilized in order to limit the excessive heat damage. Transmission electron microscopy micrographs of the cross sections of friction stir spot micro welds in lap-shear specimens were examined. These micro welds showed the failure mode of nugget pullout under lap-shear loading conditions. The experimental observations suggested that under lap-shear loading conditions, the failure was initiated near the possible original notch tip in the stir zone and the failure propagated along the circumference of the nugget to final fracture.

Intermetallic compounds in Al 6016/IF-steel friction stir spot welds

The joining of a 1.2mm thickness Al 6016 to a 2mm thickness IF-steel has been performed by friction stir spot welding (FSSW). [9] The intermetallic compounds (IMC) have been identified at the interface Al 6016/IF-steel and quantified as a function of the rotational speed and tool penetration. TEM observations indicated the presence of tangles of elliptical intermetallic compounds. $FeAl_3$, Fe_2Al_5, and $FeAl_2$ were identified depending on welding conditions. The influence of IMC on tensile shear strength has been established. An IMC layer seems necessary to improve the weld strength, but if the layer is too thick, cracks initiate and propagate easily through the hard IMC tangles.

Frictional wear evaluation of WC–Co alloy tool in friction stir spot welding

Tool wear is a key issue for the friction stir spot welding (FSSW) of steel plates, especially in the automobile industry. (10)In this study, steel plates were welded 500_ using FSSW with WC–Co alloy tools of two different compositions. The effect of the weld number on the joint strength and the tool wear characteristics were analyzed by using a non-contact, 3D measurement system, scanning electron microscopy (SEM) with energy dispersive spectrometry (EDS), and X-ray diffraction (XRD). The experimental results indicated that the tool suffered extreme wear and that the joint strength was affected by the worn tool shape after welding. This tool wear was attributed to the formation of a ternary W–Fe–O compound, oxidative wear of WC and fatigue of the Co binder. Steel plates were subjected to FSSW with two tools of different chemical composition.

2. CONCLUSION

In friction stir spot welding material flow in the stir zone is dominated by the rotation of the pin Flow transition zone, stir zone, and torsion zone is evolved due to the combination of rotational, horizontal and vertical motions of the plasticized material. In ***friction stir spot*** welding of Zr- based bulk metallic glass sheets a good correlation is found between the stirred areas, the path area and the joint resistance supports the assumption that the enlargement of the stirred zone directly affects the joint performances and explains the significant difference observed in the joint mechanical response. In Friction stir spot welding of hot-stamped boron steel the microstructure, the relationship between the unique mechanical mixing, phase transformations and failure initiation sites associated with joining martensitic steels are characterized.

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