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Friction Stir Welding Optimization Techniques: A Review

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Abstract

Friction stir welding (FSW) is a relatively new solid state joining process. The increasing use of aluminum alloys in aviation, marine and transport industries gives rise the development of new solid state joining process. This paper reviews the recent development in the friction stir welding, microstructure of friction stir welding joint and the effect of friction stir welding parameters on the mechanical properties of the joints. The development of the sound joints between dissimilar materials is of great importance in many emerging applications. In this review article more emphasis has been given to dissimilar welding of different series of aluminum alloy. Different optimization techniques has been reviewed for excellent friction stir welding joints efficiency. Application of Taguchi, Grey Relation Analysis, Particle Swarn Analysis and Response Surface Methodology in friction stir welding has been reviewed. In addition, several important key problems and issues remain to be addressed about the optimization of friction stir welding and opportunities for further research are identified.

Key words: - Friction Stir welding, Optimization Techniques, Aluminium alloys, Microstructure.

Aluminium and its alloys are widely used in aerospace, shipbuilding, automotive, marine and railway industry for high performance structural applications because of their desirable properties such as high strength to weight ratio, resistant to stress corrosion cracking, superior cryogenic properties, and good weld ability and formability [1]. Aluminium and its alloys for structural applications are mainly joined by riveting or welding. However, joining of aluminium and its alloys by riveting and welding impose many serious problems like cast brittle dendritic structure, micro porosity, solidification and liquation cracking, loss of strength due to softening in heat affected zone (HAZ) and corrosion resistance [2]. Some aluminium alloys can be resistance welded with an extensive surface preparation due to oxide formation. Though riveting can produce extremely dependable and high strength joints but it consumes more time, adds weight and distortion to the structure along with corrosion problems than those made by other methods [3]. FSW is considered to be the most remarkable and potentially useful welding technique for joining Al-alloys, Mg-alloys, Ti-alloys, steels etc. [4, 5].

In general, during FSW deformational and frictional heat is supplied from top side of the plates and combination of severe thermo mechanical stresses softened the material beneath the tool shoulder. Further, simultaneous tool rotation and traverse moves softened material from advancing side (AS) to the other side (RS) to form a joint due to dual action of extrusion and forging [6]. Distribution of thermo mechanical stresses is not uniform along transverse and longitudinal cross section of the weld [7] as maximum temperature (~ 4800c) has reported to vary from top to bottom surface and from central weld nugget zone (WNZ) to outermost HAZ [8]. Further, degree of plastic deformation and frictional heating increased with increase in rotary speed and decrease in welding speed so is the maximum temperature. Therefore, different zones of FSW joints displayed heterogeneity in microstructure and mechanical properties [9, 10]. The variation in the WNZ grain size is believed due to difference in associated temperature profile and heat dissipation [8-11] and the loss of strength as consequence FSW joints of PHAAs generally have weld strength inferior than that of the base metal. At, present parent material strength can only be achieved using base metals in annealed temper condition which cannot be softened by further heating during FSW. All these factors lead to lesser dissolution/coarsening of strengthening precipitates as well as narrowing of the softened zone [12] besides forcing different FSW zones to offer varying responses to corrosion [4]. Further, susceptibility to corrosion increases with the sanitization of the weld microstructure of FSW joints of high strength 2xxx and 7xxx series aluminium alloys [13, 14]. Process parameters have profound effect on location of corrosion, anodic reactivity, and rate of intergranular attack in case of friction stir welded AA2024-T351 [15]. Additionally, in-process cryogenic cooling improves corrosion resistance of FSW joints [16].

Pre weld temper conditions of base metal may have great influence on microstructure evolution, tensile and fatigue properties, and fracture location. Initial base metal condition also affects the selection of range of process parameters for FSW. Base metal in annealed condition can be welded at higher welding speed and offer better strength efficiency of FSW joints than that in peak aged condition [17]. FSW in peak aged condition of material reduces tool life. HAZ microstructure of FSW joints would be significantly influenced by base metal initial temper while WNZ microstructure did not [18]. FSW joints developed from AA7050 base metal in W temper would be found to be less susceptible to coarsening than T62 and T7 [19]. Fatigue specimen in T4+PWAA exhibited somewhat higher fatigue strength at high stresses while specimen in T6 condition showed better fatigue resistance at lower stresses [20].The appearance of FSW joints is smooth and there is no excess weld metal, this greatly avoids the stress concentration which in turn improves the fatigue strength of the joints than fusion welds [20, 24].

Elathasaran et al.[26] employed three parameters rotational speed, traverse speed and axial force to analyzed ultimate tensile strength, yield strength and elongation. Central composite design technique and mathematical model was developed by response surface methodology to develop relationship between FSW parameters and the response. ANOVA was used to tested adequacy of the developed empirical relationship. The material used in this investigation was AA6061-T6 and the required size was 100 mm x 50 mm x 6 mm. The welding was carried out in butt joint configuration of 20 runs. It was reported that by increasing tool rotational speed, welding speed and tool axial force, UTS and YS of the FSW joints increased up to a maximum value and then it was found decrease. By increasing tool rotational speed and axial force, TE of the joints increased but it decreased by increasing welding speed.

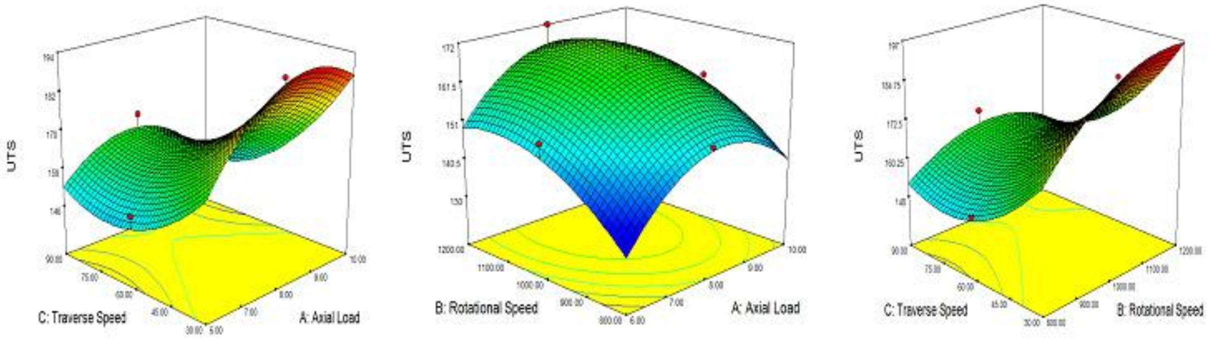


Fig 1 shows the response of Rotational Speed, Welding Feed and Axial Load on UTS

ANOVA analysis showed that the developed model can be effectively used at 95% confidence level.

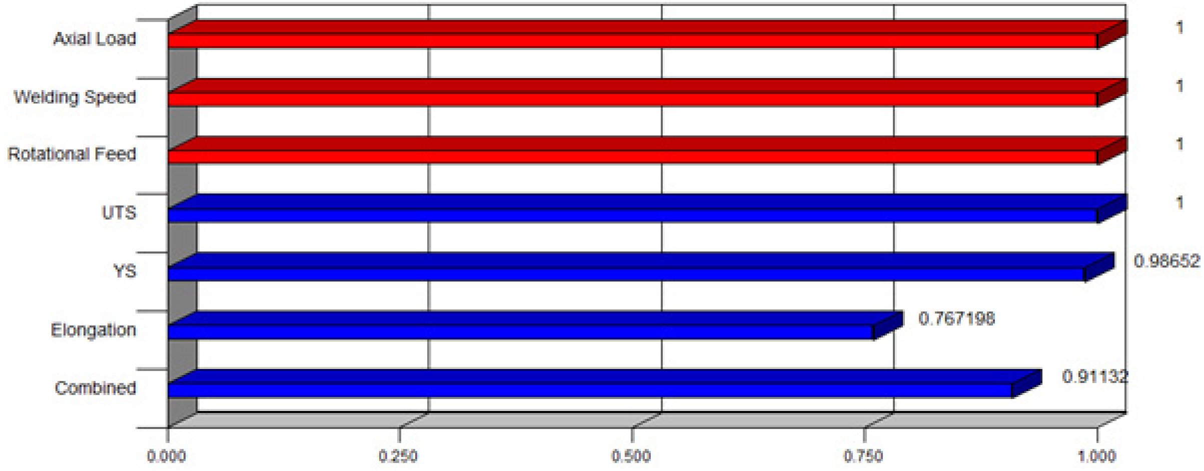
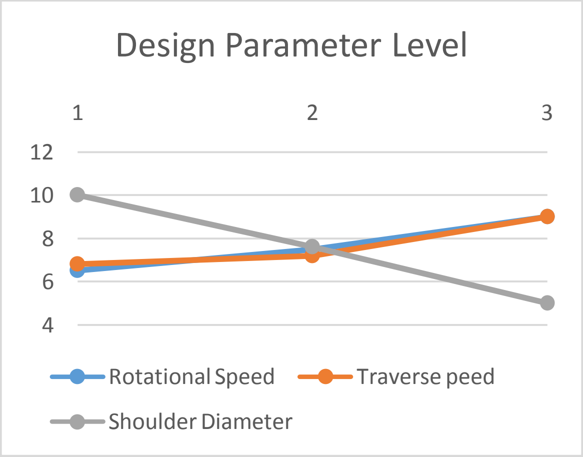


Fig. 2 Bar graph showing the maximum desirability of 0.91 for the combined objective

Hasan et al. [27] optimized microstructure and mechanical properties of FSW of AA1100 using Taguchi L9 orthogonal design of experiments. For this purpose microstructure of weld zone is simulated by the microstructure project module based on the cellular automation method of Deform-3D software. Good agreements between the simulation and the experimental results were observed. The design parameters analyzed in this experiment were tool rotational speed, traverse speed and shoulder diameter. The response are grain size, ultimate tensile strength and hardness. ANOVA was used in order to determine the most dominant factors in FSW. Traverse speed was the highly significant factor and plays a major role in affecting the grain size, hardness and UTS of weld. Increasing rotational speed and shoulder diameter led to the reduction in the tensile strength and hardness, it also increases grain size.



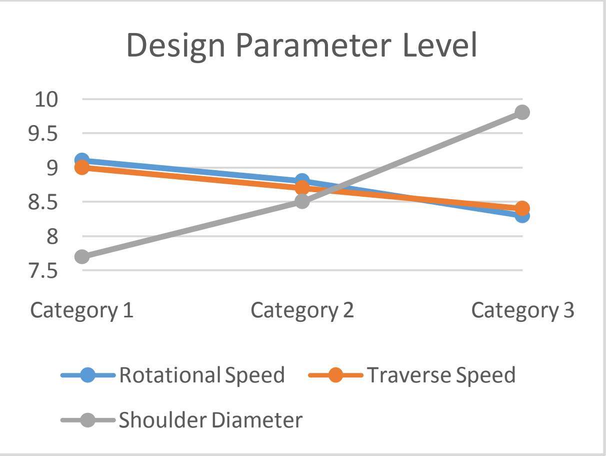
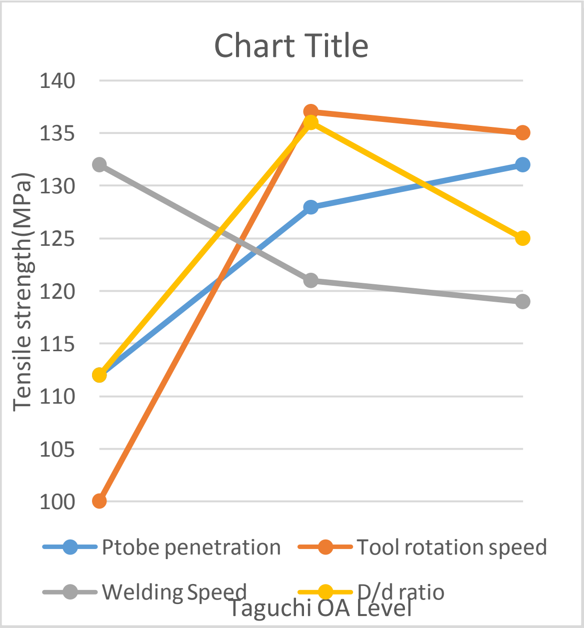


Fig. 3 Effect of process parameters on grain size. **Fig. 4 Effect of process parameters on UTS.**

Silva et al.[28] optimized Friction Stir Welding AA6082-T6 T-joints using Taguchi method for improved joint strength. L27 orthogonal Array were used for experiment. The parameter selected to optimize were tool rotation speed, welding speed and tool geometry including shoulder to probe diameter and probe length. The welds were performed in the material rolling direction. ANOVA analysis were used to find out the contribution of each parameter and linear equation for mechanical strength prediction were derived. Response surface analysis were also applied to found out the influence of each parameter and their interaction in the joint strength. It was reported that joint efficiency is of 56 % for the tensile test and 51% for yield strength regarding base metal properties. It was also reported that tool rotational speed plays an important role in joint mechanical properties. Tool rotational speed and shoulder to probe diameter ratio are strongly dependent on each other. It was also reported that welding speed did not have any significant effect on the joint strength.



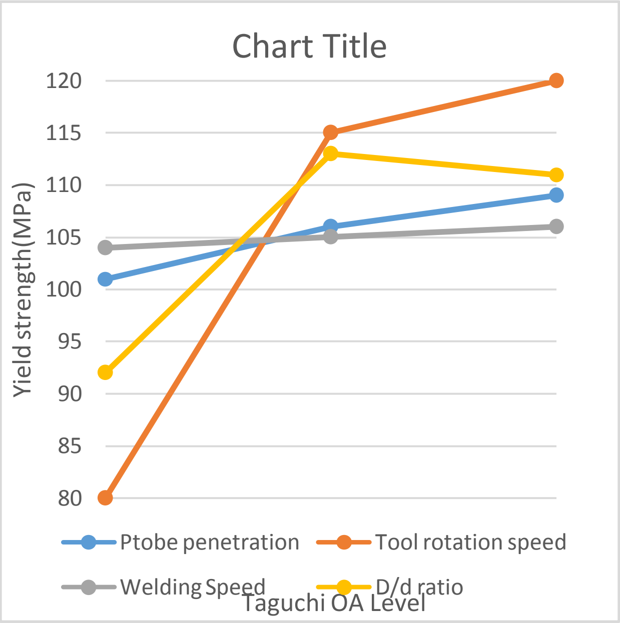
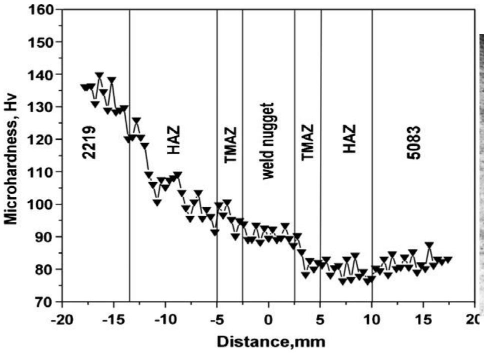
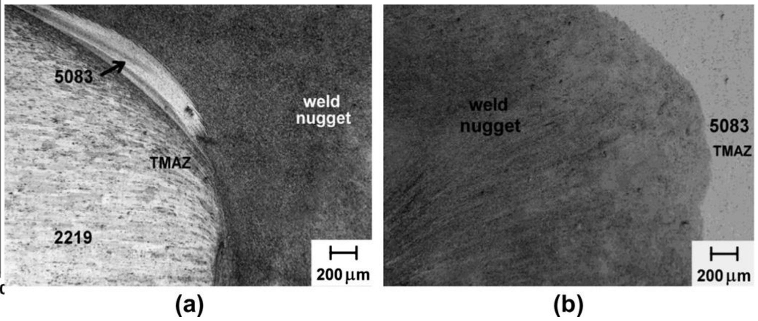


Fig. 5 **Effect of process parameters on tensile strength.**

Fig. 6 **Effect of process parameters on YS.**

Koilraj et al.[29]optimized dissimilar FSW joint of AA2219-T87 and AA5083-H321 aluminum plates of 6 mm thickness for the tensile strength. The rotational speed, traverse speed, tool geometry and ratio between tool shoulder diameter and pin diameter were taken into consideration. L16 orthogonal array were used because of four parameters at four level were taken into consideration. It was reported that ANOVA showed ratio between tool shoulder diameter and pin diameter was the most dominant factor for deciding the tensile strength of the joint. Pin geometry and welding speed were also played significant role for the soundness of the joint. It was also reported that material placed on the advancing side dominates the nugget region.

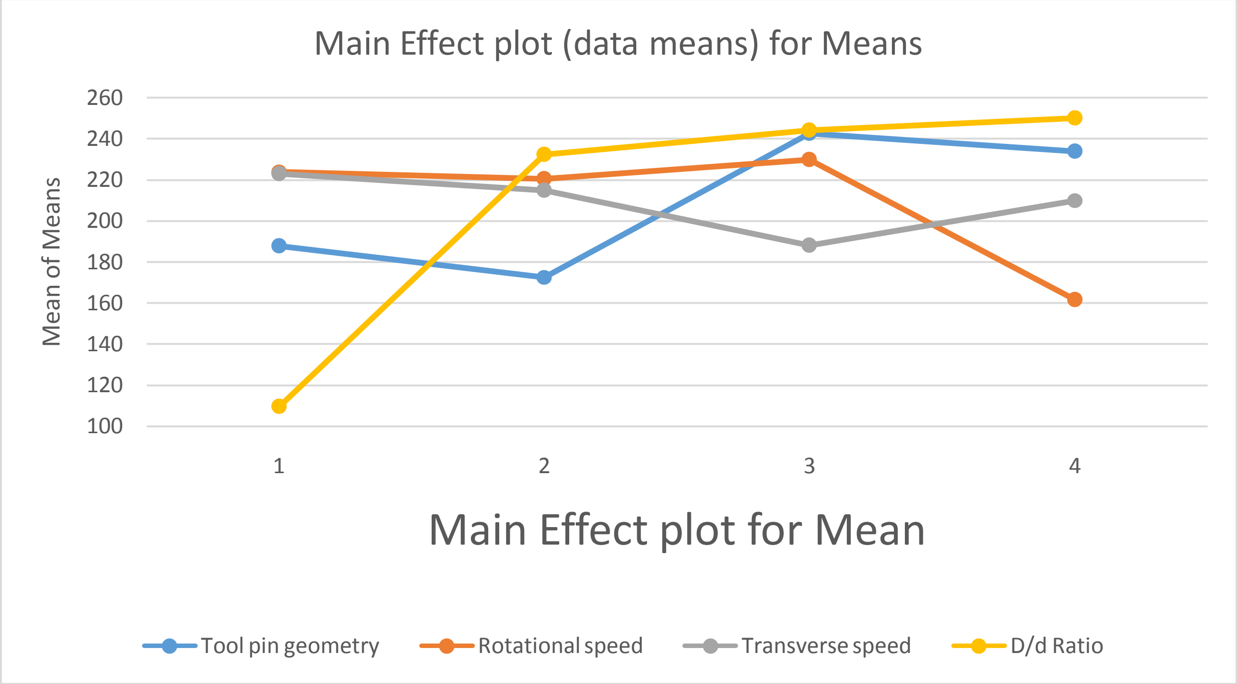


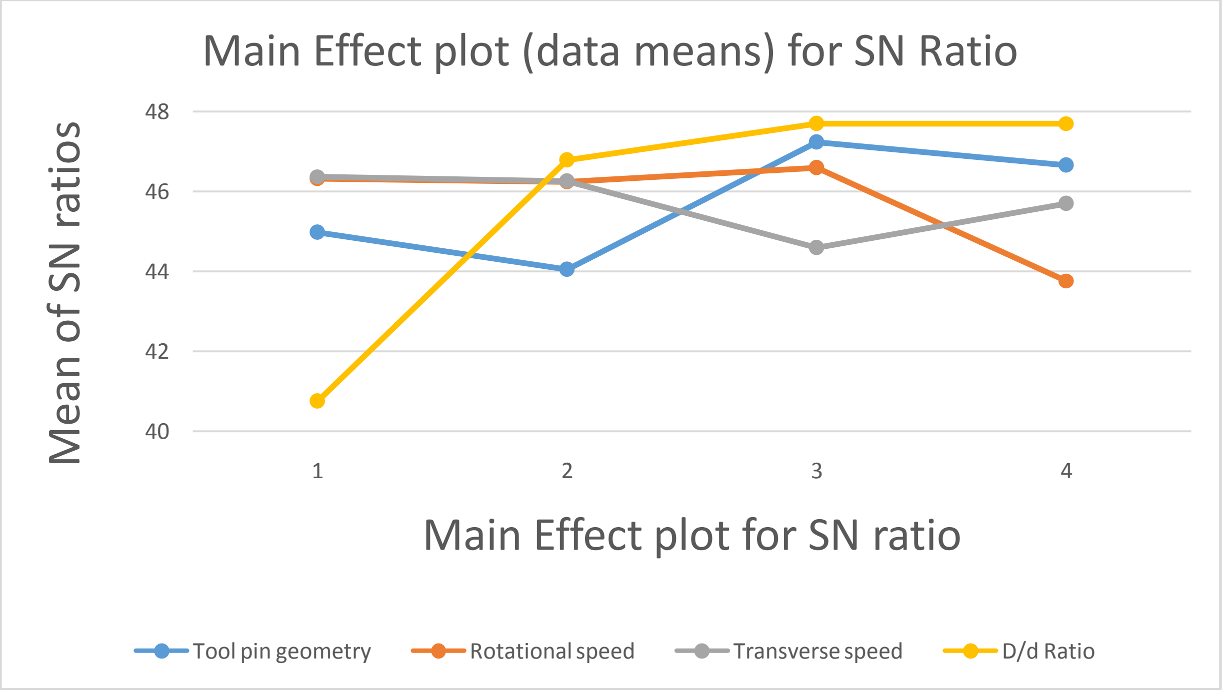


(a) (b)

Fig. 7. Microhardness profile across the weld. Fig. 8. TMAZ microstructures: (a) advancing side, and (b) retreating side.

Fig. 9. Microstructures of base materials: (a) optical, alloy 221, and (b) optical, alloy 5083.





Liu et al. [30]analyse the process parameters effect on FSW of dissimilar aluminum ally to TRIP steel. Aluminum ally 6061-T6 and high strength steel, transformation indused plasticity steel has been taken for the investigation. Two levels of rotation speed were investigated under three level of welding speed and two level of tool offset. Measurement of welding force and temperature was done for the microstructure evalution of the joint. Scanning Electron Microscopy (SEM) and Optical Microsccopy (OM) were utilized to analyze the microstructure. It was reported that the maximum ultimate tensile strength can reach 85% of the base aluminum alloy. Welding speed had an insignificant effect on welding force, temperature distribution and material strain rate and therefore the IMC layer composition. Shojaeefard et al.[31]optimized the dissimilar alloy FSW lap joint, aluminum to brass with reference to tensile shear strength of the joint. The process parameters taken into consideration were Rotational speed, tool tilt angle and traverse speed. Taguchi L9 orthogonal design of experiment were used for process parameters optimization. ANOVA was used to evaluate the significance of process parameters on tensile shear force. It was reported that tool rotation speed plays significant role and contributes 40 % of the overall contribution. It was also reported that Increasing the the tool rotational speed at constant traverse speeds resulted in increase of the tensile shear force to maximum, and then a decrease in tensile shear force occurred. The maximum value of hardness were observed in the middle of the nugget zone because of very fine recrystalized grains formation.

Elanchezhian et al. [32] optimized FSW of AA8011 and AA6062 using mathmatical method for mechanical properties. The parameters identified for investigation were tool rotation speed, weldiing speed and axial force. Experiments were conducted as per Taguchi L9 orthogonal array. ANOVA was also used to find the contribution of each parameter. Scanning Electron Microscope (SEM) technique was used to examine the quality of surface texture. It was reported that tool rotation speed was playing important role to affecting impact strength. It was also reported that welding speed has negligible influence on Tensile strength.

Summary:

Although FSW has been successfully used to join materials that are difficult-to-weld, it is still at anearly stage. So far, the development of the FSW process for each new application has remained largely empirical. Scientific knowledge-based numerical studies are of significant help in understanding theFSW process. In this paper, the research activities and progress to date in the development of numerical analysis of FSW are reviewed and their applicability to the manufacturing of components is emphasized. Firstly, different types of numerical methods and modeling techniques are considered; then the variables involved in numerical modeling of the FSW process are discussed. The microstructure behavior modeling of the FSW is described. Finally, advances in numerical analysis of mechanical characteristics of the FSW joints are presented. Many challenges remain in numerical analysis of FSW. As FSW comprises complex phenomena involving many interrelated mechanisms and thermal processes, it is clear that a complete characterization of joint behavior is impossible. Accurate and reliable numerical analysis of the FSW is still a very difficult task as the behavior of the FSW joints is influenced by different factors in combination. The references presented in this paper are by no means complete but they comprehensively represent the application of different numerical methods on the subject area. The main goal of the paper is to review recent progress in numerical analysis of FSW and to provide a basis for further research.

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