# DOWNLOAD PDF FRICTION STIR WELDING HANDBOOK

## Chapter 1 : Friction Stir Welding

*Friction Stir Welding - Quality in Depth Cleaner, leaner, stronger. In contrast to conventional welding techniques, the FSW process requires no filler material, gas or other consumables - and consumes much less energy.*

Ninth Edition, Volume 3 Welding Processes, Part 2 This authoritative resource brings together pages of comprehensive information on solid-state and other welding and cutting processes. The book includes chapters on the following welding processes: The final chapter covers various other welding and cutting processes, including modernized water jet cutting. Written, updated, and peer reviewed by a group of highly respected technical and scientific experts. Provides a comprehensive chapter on resistance welding equipment, with photos of state-of-the-art equipment and accompanied by new electrical diagrams and drawings. In addition to a chapter on friction welding, a new chapter introduces friction stir welding, the process that has users excited about its significant advantages. Discusses the most recent developments in beam technology in greatly expanded chapters on laser beam welding and cutting and electron beam welding. Presents a diverse array of processes in chapters on ultrasonic welding, explosion welding, diffusion welding and diffusion brazing, adhesive bonding, and thermal and cold spraying. Also discusses various other welding and cutting processes, including sections on two emerging processes: Includes a section on safe practices specific to the process in each chapter. This volume is devoted to information on resistance welding, solid state processes, and other joining and cutting methods. It contains updated resistance welding chapters: The chapter on friction welding been updated. New in this edition is a separate chapter on the developing process variation of friction stir welding. Other chapters explore ultrasonic welding, explosion welding, adhesive bonding, thermal spraying and cold spraying, diffusion welding, and diffusion brazing. The chapters on electron beam welding and laser beam welding and cutting contain significantly expanded technology. The last chapter, Other Welding and Cutting Processes, contains information on two new or revitalized processes, magnetic pulse welding, and electro-spark depositing. New information is presented on water jet cutting, which is reappearing in many current applications as a modern, efficient process. The chapters in this volume reflect the dramatic changes brought into the welding process over the past decade by the precise control of welding parameters made possible by digital controls and microprocessors as applied to new techniques and advanced materials. Each chapter draws on the expertise of highly qualified experts enthusiastic about the subject process and headed by a chapter chair with an admirable dedication to the details of infusing state-of-the-art information into the basics of processes. One hundred and ten volunteers contributed, representing university, government, and private welding research and development institutions, manufacturers of welding equipment and materials and manufacturers, fabricators, and welders who use this technology.

## Chapter 2 : Friction Stir Welding (FSW) | Welding Automation Robotics | Products & Solutions | ESAB

*The Friction Stir Welding process produces a joint stronger than the fusion arc welded joint, obtained in the earlier Light Weight Tank program. A significant benefit of Friction Stir Welding is that it has significantly fewer process elements to control.*

FSW uses the solid state of materials. As a result, Friction Stir Welding is not sensitive to solidification-related defects that are problematic with other welding processes. Used for aluminum welding, it also allows for heterogeneous aluminum-copper, aluminum-magnesium, and aluminum-steel welds. This paves the way for many fields of application that have been inaccessible until recently in the aeronautics, rail, naval and automobile sectors. SUNI supports you in the discovery of this innovative welding process, in its technical-economic optimization and trains your employees. FSW makes it possible to produce long lengths of aluminum welds, without any melting of the base material. This is a significant metallurgical advantage over conventional arc welding. There is no melting of the FSW base material, which eliminates the risk of solidification cracking. There are many advantages: Weld aluminum without heating or deforming it How does Friction Stir Welding work? The rotary tool is then brought into contact with the workpieces. The tool has two basic components: The length of the probe is usually designed to closely match the thickness of the pieces. Welding is initiated by dipping the rotating probe into the pieces until the shoulder is in close contact with the top surface of the component. The frictional heat is generated when the rotary shoulder rubs the upper surface with applied force. Once enough heat is generated and fed into the room, the rotating tool is propelled forward. The material is softened by the heating action of the shoulder, and transported by the probe through the connecting line, facilitating the joint. Thanks to this patented innovation, SUNI has an ultra-modular, ergonomic and economical solution, which allows, on the same carried out machine, successive operations of Friction Stir Welding and machining to be. This patented technology puts FSW welding within the reach of all companies, by dividing by 4 the cost to access to Friction Stir Welding. The machiners trained by SUNI and Stirweld confirm the time to get grips with the technology is ultra-fast. If you are equipped with a tooling machine and FSW interests you, SUNI can offer you this innovative, modular, ergonomic and economical solution. Weld your aluminum alloys You are working with aluminum and looking to improve the quality of the welding of your parts, discover FSW. The advantages of the process result from the fact that the FSW process takes place in the solid state below the melting point of the materials to be assembled. The major advantage of the process is the ability to assemble materials that are difficult to weld by fusion, for example 2xxx and 7xxx aluminum alloys, steel, and copper. Friction Stir Welding can use equipment designed for the purpose or a modified tooling machine technology. The process is also suited to automation and is adaptable to the use with robots. The FSW has other mechanical advantages: It preserves excellent mechanical properties in fatigue, traction and bending tests. In addition the FSW process can work in any position. You realize savings of use, as FSW is a technology with low consumption. In addition, a tool can generally be used for a weld length of up to m in aluminum alloys of the 6xxx series. And no filler wire is required. Ecologically efficient, Friction Stir Welding does not require protection against gases for welding aluminum. In addition, you will save a lot of preparation time, since the FSW has a certain tolerance for imperfect solder preparations â€” thin layers of oxide can be accepted. No grinding, brushing or stripping is required in mass production. Would you like to integrate FSW internally? How to make this technological leap? If you decide to adopt FSW, you will have access to a rental system allowing optimal flexibility of your machine park. Interested in FSW projects?

## Chapter 3 : Friction Stir Welding (FSW)

*4 5 Introduction to the FSW Technical Handbook Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first.*

Principle of operation[ edit ] Two discrete metal workpieces butted together, along with the tool with a probe The progress of the tool through the joint, also showing the weld zone and the region affected by the tool shoulder A rotating cylindrical tool with a profiled probe is fed into a butt joint between two clamped workpieces, until the shoulder, which has a larger diameter than the pin, touches the surface of the workpieces. The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the tool is moved forward, a special profile on the probe forces plasticised material from the leading face to the rear, where the high forces assist in a forged consolidation of the weld. This process of the tool traversing along the weld line in a plasticised tubular shaft of metal results in severe solid-state deformation involving dynamic recrystallization of the base material. The micro-structure can be broken up into the following zones: The stir zone also known as the dynamically recrystallised zone is a region of heavily deformed material that roughly corresponds to the location of the pin during welding. The grains within the stir zone are roughly equiaxed and often an order of magnitude smaller than the grains in the parent material. The flow arm zone is on the upper surface of the weld and consists of material that is dragged by the shoulder from the retreating side of the weld, around the rear of the tool, and deposited on the advancing side. In this region the strain and temperature are lower and the effect of welding on the micro-structure is correspondingly smaller. Unlike the stir zone, the micro-structure is recognizably that of the parent material, albeit significantly deformed and rotated. Although the term TMAZ technically refers to the entire deformed region, it is often used to describe any region not already covered by the terms stir zone and flow arm. As indicated by the name, this region is subjected to a thermal cycle but is not deformed during welding. The temperatures are lower than those in the TMAZ but may still have a significant effect if the micro-structure is thermally unstable. In fact, in age-hardened aluminum alloys this region commonly exhibits the poorest mechanical properties. Issues such as porosity , solute redistribution, solidification cracking and liquation cracking do not arise during FSW. In general, FSW has been found to produce a low concentration of defects and is very tolerant to variations in parameters and materials. Insufficient weld temperatures, due to low rotational speeds or high traverse speeds, for example, mean that the weld material is unable to accommodate the extensive deformation during welding. This may result in long, tunnel-like defects running along the weld, which may occur on the surface or subsurface. Low temperatures may also limit the forging action of the tool and so reduce the continuity of the bond between the material from each side of the weld. The light contact between the material has given rise to the name "kissing bond". This defect is particularly worrying, since it is very difficult to detect using nondestructive methods such as X-ray or ultrasonic testing. If the pin is not long enough or the tool rises out of the plate, then the interface at the bottom of the weld may not be disrupted and forged by the tool, resulting in a lack-of-penetration defect. This is essentially a notch in the material, which can be a potential source of fatigue cracks. A number of potential advantages of FSW over conventional fusion-welding processes have been identified: Improved safety due to the absence of toxic fumes or the spatter of molten material. Can operate in all positions horizontal, vertical, etc. Can use thinner materials with same joint strength. General performance and cost benefits from switching from fusion to friction. However, some disadvantages of the process have been identified: Exit hole left when tool is withdrawn. Large down forces required with heavy-duty clamping necessary to hold the plates together. Less flexible than manual and arc processes difficulties with thickness variations and non-linear welds. Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required. Important welding parameters[ edit ] Tool design[ edit ] Advanced friction stir welding and processing tools by MegaStir shown upside down The design of the tool [16] is a critical factor, as a good tool can improve both the quality of the weld and the maximal possible welding speed. It is desirable that the tool material be sufficiently strong, tough, and hard wearing at the welding temperature. Further, it should have a good oxidation resistance and a low thermal conductivity to minimise heat loss and thermal damage to the machinery further up the drive train. Hot-worked tool steel such as AISI H13 has proven perfectly acceptable for welding aluminium alloys within thickness ranges of 0. Improvements in tool design have been shown to cause substantial improvements in productivity and quality. TWI has developed tools specifically designed to increase the penetration depth and thus increasing the plate thicknesses that can be successfully welded. An example is the "whorl" design that uses a tapered pin with re-entrant features or a variable-pitch thread to improve the downwards flow of material. Additional designs include the Triflute and Trivex series. The Triflute design has a complex system of three tapering, threaded re-entrant flutes that appear to increase material movement around the tool. The Trivex tools use a simpler, non-cylindrical, pin and have been found to reduce the forces acting on the tool during welding. The majority of tools have a concave shoulder profile, which acts as an escape volume for the material displaced by the pin, prevents material from extruding out of the sides of the shoulder and maintains downwards pressure and hence good forging of the material behind the tool. The Triflute tool uses an alternative system with a series of concentric grooves machined into the surface, which are intended to produce additional movement of material in the upper layers of the weld. Widespread commercial applications of friction stir welding process for steels and other hard alloys such as titanium alloys will require the development of cost-effective and durable tools. These two parameters have considerable importance and must be chosen with care to ensure a successful and efficient welding cycle. The relationship between the rotation speed, the welding speed and the heat input during welding is complex, but in general, it can be said that increasing the rotation speed or decreasing the traverse speed will result in a hotter weld. In order to produce a successful weld, it is necessary that the material surrounding the tool is hot enough to enable the extensive plastic flow required and minimize the forces acting on the tool. If the material is too cold, then voids or other flaws may be present in the stir zone and in extreme cases the tool may break. Excessively high heat input, on the other hand, may be detrimental to the final properties of the weld. Theoretically, this could even result in defects due to the liquation of low-melting-point phases similar to liquation cracking in fusion welds. These competing demands lead onto the concept of a "processing window": Tool tilt and plunge depth[ edit ] A drawing showing the plunge depth and tilt of the tool. The tool is moving to the left. The plunge depth is defined as the depth of the lowest point of the shoulder below the surface of the welded plate and has been found to be a critical parameter for ensuring weld quality. Tilting the tool by 2â€"4 degrees, such that the rear of the tool is lower than the front, has been found to assist this forging process. The plunge depth needs to be correctly set, both to ensure the necessary downward pressure is achieved and to ensure that the tool fully penetrates the weld. Given the high loads required, the welding machine may deflect and so reduce the plunge depth compared to the nominal setting, which may result in flaws in the weld. On the other hand, an excessive plunge depth may result in the pin rubbing on the backing plate surface or a significant undermatch of the weld thickness compared to the base material. Variable-load welders have been developed to automatically compensate for changes in the tool displacement, while TWI have demonstrated a roller system that maintains the tool position above the weld plate. Welding forces[ edit ] During welding, a number of forces will act on the tool: Some friction-stir welding machines operate under load control, but in many cases the vertical position of the tool is preset, and so the load will vary during welding. The traverse force acts parallel to the tool motion and is positive in the traverse direction. Since this force arises as a result of the resistance of the material to the motion of the tool, it might be expected that this force will decrease as the temperature of the material around the tool is increased. The lateral force may act perpendicular to the tool traverse direction and is defined here as positive towards the advancing side of the weld. In order to prevent tool fracture and to minimize excessive wear and tear on the tool and associated machinery, the welding cycle is modified so that the forces acting on the tool are as low as possible, and abrupt changes are avoided. In order to find the best combination of welding parameters, it is likely that a compromise must be reached, since the conditions that favour low forces e. Flow of material[ edit ] Early work on the mode of material flow around the tool used inserts of a different alloy, which had a different contrast to the normal material when viewed through a microscope, in an effort to determine where material was moved as the tool passed. In this model the rotation of the tool draws little or no material around the front of the probe; instead, the material parts in front of the pin and passes down either side. After the material has passed the probe, the side pressure exerted by the "die" forces the material back together, and consolidation of the join occurs, as the rear of the tool shoulder passes overhead and the large down force forges the material. More recently, an alternative theory has been advanced that advocates considerable material movement in certain locations. The researchers used a combination of thin copper strip inserts and a "frozen pin" technique, where the tool is rapidly stopped in place. They suggested that material motion occurs by two processes: Material on the advancing side of a weld enters into a zone that rotates and advances with the profiled probe. This material was very highly deformed and sloughs off behind the pin to form arc-shaped features when viewed from above i. It was noted that the copper entered the rotational zone around the pin, where it was broken up into fragments. These fragments were only found in the arc-shaped features of material behind the tool. The lighter material came from the retreating side in front of the pin and was dragged around to the rear of the tool and filled in the gaps between the arcs of advancing side material. This material did not rotate around the pin, and the lower level of deformation resulted in a larger grain size. The primary advantage of this explanation is that it provides a plausible explanation for the production of the onion-ring structure. The marker technique for friction stir welding provides data on the initial and final positions of the marker in the welded material. The flow of material is then reconstructed from these positions. Detailed material flow field during friction stir welding can also be calculated from theoretical considerations based on fundamental scientific principles. Material flow calculations are routinely used in numerous engineering applications. Calculation of material flow fields in friction stir welding can be undertaken both using comprehensive numerical simulations [28] [29] [30] or simple but insightful analytical equations. At the same time, it is necessary to ensure that the temperature around the tool is sufficiently high to permit adequate material flow and prevent flaws or tool damage. When the traverse speed is increased, for a given heat input, there is less time for heat to conduct ahead of the tool, and the thermal gradients are larger. At some point the speed will be so high that the material ahead of the tool will be too cold, and the flow stress too high, to permit adequate material movement, resulting in flaws or tool fracture. If the "hot zone" is too large, then there is scope to increase the traverse speed and hence productivity. The welding cycle can be split into several stages, during which the heat flow and thermal profile will be different: The material is preheated by a stationary, rotating tool to achieve a sufficient temperature ahead of the tool to allow the traverse. This period may also include the plunge of the tool into the workpiece. When the tool begins to move, there will be a transient period where the heat production and temperature around the tool will alter in a complex manner until an essentially steady state is reached. Although fluctuations in heat generation will occur, the thermal field around the tool remains effectively constant, at least on the macroscopic scale. Near the end of the weld, heat may "reflect" from the end of the plate, leading to additional heating around the tool. Heat generation during friction-stir welding arises from two main sources: Mathematical approximations for the total heat generated by the tool shoulder Qtotal have been developed using both sliding and sticking friction models:

## Chapter 4 : Friction stir welding - Wikipedia

*In addition to a chapter on friction welding, a new chapter introduces friction stir welding, the process that has users excited about its significant advantages. Discusses the most recent developments in beam technology in greatly expanded chapters on laser beam welding and cutting and electron beam welding.*

## Chapter 5 : AWS Bookstore. AWS WHC - FRICTION STIR WELDING

*The Friction Stir Welding (FSW) is a latest process of Advanced Welding Technology and was invented in by The Welding Institute (TWI) at Cambridge, in United Kingdom.*

## Chapter 6 : AWS Welding Handbook

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*Chapter 7 from the Welding Handbook, Ninth Edition, Volume 3, "Welding Processes, Part 2," has been selected by the AWS Product Development Committee as a service to industry professionals. Information in this chapter provides a basic understanding of the friction stir welding process and a variation of the process, friction stir spot welding.*

## Chapter 7 : AWS Bookstore. Friction Welding - Results

*Friction Stir Welding. Friction stir welding is a method of solid state welding which heats base metals over the plasticity temperature range using heat produced by friction between the stir head and the base metal.*

## Chapter 8 : SUNI France FSW- Friction Stir Welding - new technologies

*Friction stir welding (FSW) is a solid-state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece material. Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool.*