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Review Article

A Review on the Effect of Cryogenic Treatment on the Mechanical Properties of Friction Stir Welded Joints

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Abstract

If we talk about the thermal processing of metals, it is nothing new. Heat treatment of metals dates back to thousands of years. Metal characteristics have been altered by using various heat treatment processes. But the treating the metals at the cold temperature especially at very cold temperature in the cryogenic range is relatively new and has not been accepted fully in the manufacturing industries. This paper focuses on the change of mechanical properties of Friction Stir Welded joints after cryogenic treatment process.

Keywords: Friction Stir Welding, Cryogenic treatment, Wear resistance, Mechanical properties

Introduction

Simple heat treatment process consists of three basic operations: Firstly, we bring the temperature of the given material at the fixed range. Secondly, maintaining the temperature for some duration. Thirdly, bringing back the given material to the room temperature. These all operations are carried out in precise manner and under controlled condition. We can apply these steps with other various operations in various combinations. The heating and quenching steps are combined in specific ways to produce any of several outcomes, such as annealing, hardening, or tempering. In some cases, the intent is to change the metal through its entire cross section (through hardening); in others, the goal is to change the material at or near the surface (case hardening). The results can be changes in tensile strength, shear strength, compressive strength, ductility, toughness, and so on—essentially any mechanical property of the metal.

Cryogenics is basically coming from the *kryo* which means very cold; from greek language this word has come and *genics* means to produce. So, basically cryogenic means, science and technology associated with generation of low temperature below 123 kelvin. Cryogenic treatment is the process of cooling materials to cryogenic temperatures temporarily to improve their material properties at room temperature. This is distinct from cooling materials down to cryogenic temperatures to take advantage of phenomena such as superconductivity that only occur at cryogenic temperatures. Cryogenic treatment, sometimes also referred to as deep cryogenic treatment, is best thought of as an adjunct to other material processing steps such as heat treatment, quenching and cold work.

Many studies have focused on improving the properties of metals by deep cryogenic treatment. Positive effects have been noticed in tool steels, carburized steels, cast irons and other materials. Depending on both the process applied and the material used, a number of material properties may be improved, including hardness, wear resistance (thus increasing lifetime), fatigue life and electrical conductivity. As an example, Barron (1982) described an increase of wear resistance of tool steel treated down to 77 K and ascribed the cause to a more complete transition from the austenite phase to the harder martensite phase.

Cryogenic Process consists of four stages [1], that involves: 1) Austenitization: Heating from room temperature to its austenitizing temperature (around 1100 °C), at an

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extremely slow rate ranging from 0.5 to 1.5°C /min 2) Cooling: Direct cooling from austenitizing temperature to -196 °C at the rate of 1.5 to 2 °C. It is also called as quenching. 3) Soaking: For a period of time ranging from 24 to 36 hours depends upon which material is to be treated 4) Heating: From -196 °C to room temperature at the rate of 0.5 to 1°C /min 5) Tempering: Reheating the metal at predetermined temperatures which are lower than the transformational temperature (around 150 °C) to obtain different combinations of mechanical properties in the material.

Friction stir welding (FSW) is a relatively new joining process that has been used for high production since 1996. Because melting does not occur and joining takes place below the melting temperature of the material, a high-quality weld is created. This characteristic greatly reduces the ill effects of high heat input, including distortion, and eliminates solidification defects. Friction stir welding also is highly efficient, produces no fumes, and uses no filler material, which make this process environmentally friendly.

Friction stir welding was invented by The Welding Institute (TWI) in December 1991. TWI filed successfully for patents in Europe, the U.S., Japan, and Australia. TWI then established TWI Group-Sponsored Project 5651,"Development of the New Friction Stir Technique for Welding Aluminium," in 1992 to further study this technique.

The development project was conducted in three phases. Phase I proved FSW to be a realistic and practical welding technique, while at the same time addressing the welding of 6000 series aluminium alloys. Phase II successfully examined the welding of aerospace and ship aluminium alloys, 2000 and 5000 series, respectively. Process parameter tolerances, metallurgical characteristics, and mechanical properties for these materials were established. Phase III developed pertinent data for further industrialization of FSW.

Since its invention, the process has received world-wide attention, and today FSW is used in research and production in many sectors, including aerospace, automotive, railway, shipbuilding, electronic housings, coolers, heat exchangers, and nuclear waste containers.

FSW has been proven to be an effective process for welding aluminium, brass, copper, and other low-melting-temperature materials. The latest phase in FSW research has been aimed at expanding the usefulness of this procedure in high-melting-temperature materials, such as carbon and stainless steels and nickel-based alloys, by developing tools that can withstand the high temperatures and pressures needed to effectively join these materials.

In FSW, a cylindrical, shouldered tool with a profiled probe is rotated and slowly plunged into the weld joint between two pieces of sheet or plate material that are to be welded together (Figure 1). The parts must be clamped onto a backing bar in a manner that prevents the abutting joint faces from being forced apart or in any other way moved out of position.

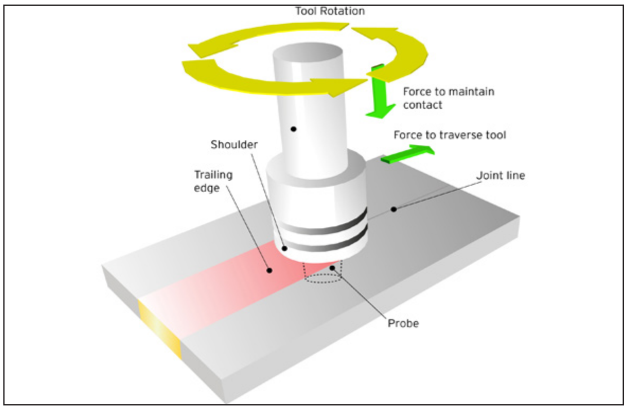

Figure 1.Schematic diagram of Friction Stir Welding process

Friction stir welding is extensively used by NASA to join large portions of aluminium for their space shuttle external fuel tank at the Michoud research facility. It is the preferred NASA welding technique for their moon rocket. As friction stir welding advances and is used in more applications, tool materials will need to be selected for optimal weld efficiency. NASA is leveraging key technologies like friction stir welding from the Space Shuttle Program to design and manufacture the Space Launch System.

The main objective of this paper is to study the effect of cryogenic treatment on the mechanical properties of various Friction Stir Welded joints.

Effect of cryogenic treatment on Friction Stir Welded joints

Singh *et al.*[2] investigated the feasibility of fabricating aerospace aluminium alloys AA2014-T651 and AA7075-T651 using friction stir welding technique. Two specimens for each joint were tested for tensile strength in as weld condition. Remaining one specimen for each experiment was subjected to post weld cryo treatment (PWCT). The specimens were deep cryo treated at -196 degree Celsius for 24 hours and afterward tested for tensile strength. Microhardness was investigated using a Vickers hardness tester at a load of 50 g for a dwell period of 12 sec. Three levels were selected from top to bottom surface on which values of microhardness were observed at intervals of 1 mm.

Senthilkumar *et al.*[3] investigated the mechanical and metallurgical properties of friction welded dissimilar aluminium joints namely AA6061-T6 & AA7079-T6 under cryogenic treatment process. The specimens were subjected to cold temperatures such as -90 degree Celsius, which is achieved by submerging them inside dry ice for long

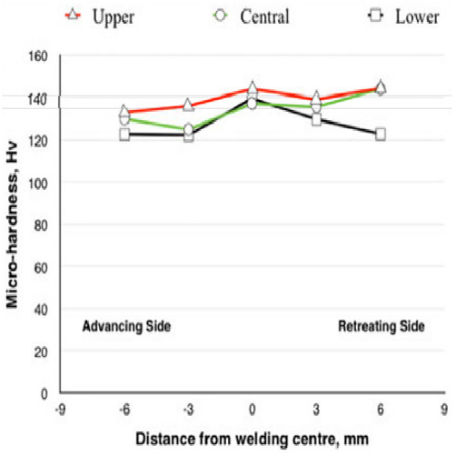

Figure 2.Hardness distribution in welding specimen

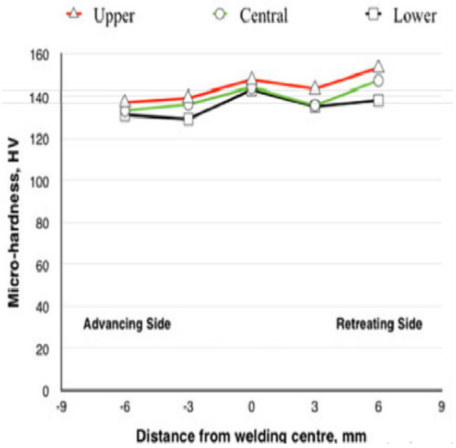

Figure 3.Hardness distribution in PWCT specimen

duration. It was observed that there was increase in the tensile strength of the samples which were subjected 72Hrs. At the period of 48Hrs, the tensile strength was reduced. So in that while increasing the duration of time period the samples are given more strength while compare to room temperature, it was reduced. Also, percentage of elongation also increased at 7Hrs. This shows that the ductility was improved at subzero treatment which have evident results in tensile strength. There was no significant improvement rather than reduce in tensile strength for 48Hrs, but for 72Hrs there was an increase in maximum tensile strength of 224Mpa.

Naveenkumar *et al.* [4] investigated the effect of cryogenic treatment on the tool material in Friction Stir Welding of copper. It was observed that cryotreatment of tool steel improves the wear resistance by conversion of retained austentite to hard phase martensite.

Jangra *et al* [5] investigated the tensile strength of the cryogenic treated friction stir welded joints of AA6082 T6 alloys. It was observed that the UTS decreases with increasing tool rotation speed while it increases with increasing weld speed (traverse speed) as shown in the Figure 4. Intense plastic deformation and frictional heating during FSW results in significant microstructural evolution within and around the stirred zone, i.e. nugget zone, thermo-mechanically affected zone (TMAZ) and heat- affected zone (HAZ) which leads to substantial change in post weld mechanical properties. Higher tool rotation rates generate higher temperature because of higher friction heating and results in more intense stirring and mixing of material. The increase in peak temperature of FSW thermal cycle leads to generation of coarse recrystallized grains, remarkable grain growth and dissolved precipitates,1 which increases the ductility of the joint. Hence, UTS decreases. Increasing weld speed means lesser time for thermal cycle, hence peak cycle temperature will lower down which results in a reduction in the recrystallized grain size. Thus UTS increases.

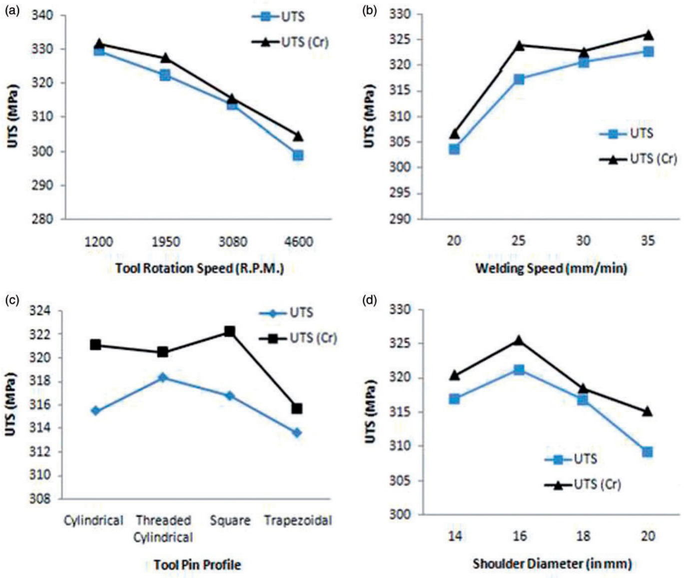

Figure 4.Variation of UTS with process parameters. UTS: ultimate tensile strength

Conclusion

Cryogenic treatment is used for improving the mechanical characteristics of Friction Stir Welded joints. Cryogenic treatment improves the performance of material by improving the martensite structure. Cryogenic treatments enhances the material's strength, hardness, wear resistance, ductility, & toughness, fine grain size, removes internal stresses, to improve machinability, cutting properties of tools, to improve surface properties, electrical properties & magnetic properties. But the mechanism by which cryogenic treatment enhances the mechanical properties of the Friction Stir Welded joints is not clearly understood.

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