Studies on Mechanical characterization of Friction Stir Welded Polyethylene Joints

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***Abstract*—Friction stir welding is a solid state welding process suitable for producing joints, especially in lightweight materials, which are particularly interesting due to the weight saving potential. The plunging of a specially designed non-consumable and rotating tool creates a connection between the sheets through frictional heat and plastic deformation. Minimum material loss is observed, and therefore a fully consolidated joint with flat surface is obtained. The aim of the present work is to investigate the mechanical properties of butt joints produced by friction stir welding (FSW) in high density polyethylene sheets of 6 mm thickness. The mechanical properties namely tensile strength and bending strength tests were carrying out on welded specimens. The results obtained were compared with parent materials strength, it is observed that polyethylene sheets could be Friction Stir welded with joint characteristics similar to base material. This could be accomplished by operating with a high rotational speed. in addition parameters such as rotational speed, plunge depth and dwell time on polyethylene joints were investigated.**

***Key words*— Friction Stir Welding, Polyethylene, Mechanical Properties.**

I. INTRODUCTION

Engineering polymers enjoy a fast development even in industrial sectors where they used to be unimaginable so far. Simultaneously with this the need for more advanced forms of joining technologies also increases that render the application of new materials more reliable. There is no new structural material if it cannot be joined by a proper technology and cannot be included into existing engineering structures. It is an important tendency nowadays that the borderlines of so far strictly separated metal, polymer and ceramic structures become somewhat blurred and by the combination of these new materials are being developed. A good example of this is the new joining technology presented in this paper, friction stir welding. Friction stir welding (FSW) is a rapidly maturing solid state joining process that appears as a promisingly ecologic weld method that enables to diminish material waste and to avoid radiation and harmful gas emissions usually associated with the conventional fusion welding techniques. The weld is formed by the excessive deformation of the material at temperatures below its melting point, thus the method is a solid state joining technique hence here is no melting of the material, so FSW has several advantages over the commonly used fusion welding techniques, such as there is no porosity or cracking in the weld region, there is no significant distortion of the workpieces (particularly in thin plates), and there is no need for filler materials, shielding gases and costly weld preparation during this joining process. Rheological properties of polymers (visco elasticity) are different from those of metals, so especially in friction stir welding, where the resulting flow fields play an especially important role, the joint strength strongly depends on the tool used. Because of these factors the FSW method to be used in polymers requires special tools and the effect of welding parameters depends on the geometry of these tools.

High Density Polyethylene (HDPE): It is a harder, more opaque and an extremely strong thermoplastic that has been used in the drinking water and waste water transport industries for decades. Not to be confused with Polyvinyl chloride (PVC), the molecular structure of HDPE will not break down or deteriorate during the life of the product. HDPE is also extremely durable and flexible, has an exceptional strength-to-weight ratio, and does not suffer from the environmental and possible health related problems seen in PVC (that emit harmful chemicals into the air and water). HDPE is commonly recycled, and has the number "2" as its recycling symbol. In 2007, the global HDPE market reached a volume of more than 30 million tons.

[1]Have selected polyethylene sheet of 3mm thick were friction stir welded with a cylindrical steel pin; two pin diameters and a combination of feed rates and rotational speed of the pin were considered for the experimentation. The pin rotational speed was changed between 3,000 and 20,000 rpm, the feed rate between 10 and 44mm/min, the pin diameter between 1 and 3mm. The joint strength was measured by means of tensile strength and concluded that a very high strength may be obtained(close to the strength of base material). [2] was investigated the weldability of high density polyethylene sheets via heat assisted friction stir welding and effect of process parameters on microstructure and mechanical properties of welded plates. Tensile and bend tests were done in order to evaluate mechanical behavior of material. It can be examined that a rotational speed of 1600rpm and welding speed of 20mm/min with an increase in heater temperature, ultimate tensile and flexural strength increases up to base material strength. From microstructure observation shows the uniform distribution of grains in the weld zone. [3] In this paper, acrylonitrile butadiene styrene (ABS) sheets were joined using a fixed heated shoe called "hot shoe" while a rotating pin through this shoe stirs melted material. Rotating speed of the pin, travelling speed, and shoe temperature at the beginning of the welding procedure were considered as varying parameters. Found that high rotational speed leads to better mixing of welding material and higher tensile strength. It was also observed that because of different material flow in the advancing and retreating side of the welding samples,

a lack of material on the retreating side of the weld occurred and lead to brittle failure in that area. [4] Have carried out the optimization of welding parameters for friction stir spot welding of high density polyethylene sheets and studied the effect of various process parameters such as tool rotation speed and welding speed and found that weld microstructure and strength depends on process parameters. [5] In this study, three-level process parameters; tool rotation speed, tool traverse speed and tilt angle were analyzed. The joint efficiency was evaluated by means of the ultimate tensile tests (UTS). The tensile tests were carried out according by a universal type tensile test machine. Tensile strength is the main characteristic recognized in this study defining the quality of FSW joints of HDPE sheets. [6] The aim of the present experimentation is to evaluate the mechanical properties of polyethylene butt welded joint formed by Friction Stir Welding. In this process there is no extra addition of coating of any other material but material is deformed under huge compressive load using friction stir welding equipment with the application of cylindrical HSS flat tool. The tool is rotated at a constant speed and moves transversely on the surface. Tensile tests have very good results as compared to base material but elongation was low, bending test showed that the welded material bent more than the parent material.FSW of $Al6061/Al_2O_3/20p$ resulted in defect free high quality welds indicates that the FSW process has the required robustness for industrial application [7].

1.1 General properties of HDPE

Table 1. Properties of HDPE

Density(g/cm^3)	**Tensile strength (MPa)**	**Elongation (%)**	**Flexural strength(MPa)**	**Melting point ^oC**
0.94	18	>300	28	120-130

1.2 FSW Operation

In the friction stir welding, a non consumable tool attached with a specially designed pin was inserted to the butting edges of the sheets to be joined. The tool shoulder had to touch the sheet surface. Under this condition the tool was rotated and traversed along the bond line. Thus, frictional heat was generated.

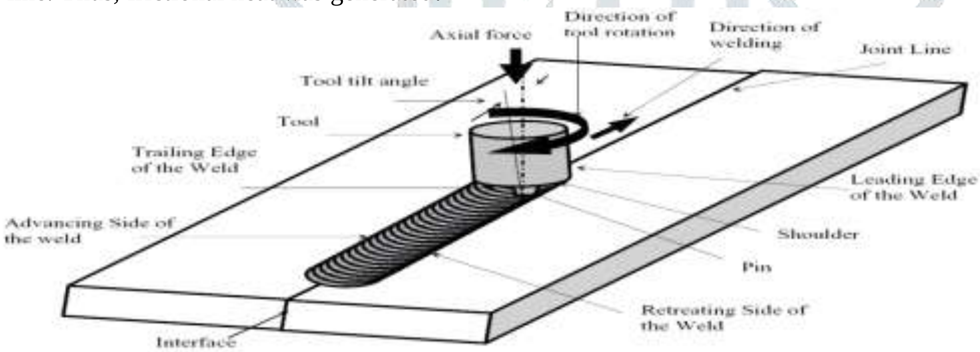

Fig.1. Friction stir welding operation

The microstructure of FSW joints can be separated into four zones: (1) parent material; (2) heat affected zone (HAZ); (3) thermo-mechanical affected zone (TMAZ); and (4) weld nugget. Schematic cross section of a typical FSW weld showing four distinct zones [8]. is presented in Figure 2.

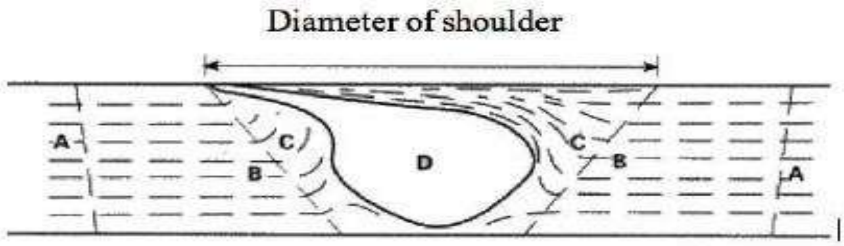

Fig.2.Schematic cross section of a typical FSW weld showing four distinct zones: (A) Base Metal (B) Heat Affected (C) Thermomechanically affected and (D) Stirred (nugget) zone.

II. METHODOLOGY

Trial experiments were carried out according to the principles of the design of the experiments in order to determine the effect of the main process parameters. The experimental studies were performed using commercial 150x 70 x6 mm dimension high density polyethylene (HDPE) sheets to fix the operating range of FSW process parameters. The FSW tool, with a 12 mm diameter shoulder and a pin with a diameter of 4.2 mm was made from high speed steel. The pin was plunged into the HDPE sheets at the joint line up to the shoulder touching the surface of the HDPE sheets. The process parameters investigated under multiple levels. Pin rotational speeds were 550, 750 and 950 rpm. To make a judgment about the effects of welding parameters on mechanical properties of the welded plates, every parameter was investigated separately, while the others were kept fixed. To ensure that shoulder applies enough pressure on work pieces, a tool-offset depth is required during plunge step of the process. The joint efficiency was evaluated by means of the ultimate tensile test and bending tests.

The process utilizes equipment that is similar to a machine tool, for which the welding conditions are preset. Therefore, the process can provide good reproducibility, and is not dependent on operator skill. The earliest feasibility studies were conducted on a modified, continuous-drive, friction-stir welding machine. Practical use necessitated increased welding capacity.The ability to use converted machine tools offers a low-cost option in the technology of friction stir welding.

Fig.3.friction stir welding machine

II. RESULTS AND DISCUSSIONS

Fig.4. Friction stir welded polyethylene joint.(550rpm and 2.53 Tonnes).

At the rotational speed of 550rpm a low amount of heat is transferred to the material due to friction. So that the weld strength was too low,load applied during process is 2.53 Tonnes.

Fig. 5. Friction stir welding of polyethylene (750rpm and 2.68 Tonnes).

Fig. 6. Friction stir welding of polyethylene (950rpm and 2.94 Tonnes).

At the rotational speed of 750rpm, the appearance of quality of the joint was inadequate. Also the joint strength is weak. At the rotational speed of 950rpm a higher amount of heat is transferred to the material due to friction. Also at this speed a very high strength may be obtained close to the strength of base material.

Table 2. Tensile result tabulation before and after weld

specimen number	Rotational speed Rpm	Tensile strength N/mm^2
1	550	4.29
2	750	8.64
3	950	15.59
4	950	17.34
5	950	17.30
6	950	24.86
7	Un welded	24.62

Fig 7.Tensile test specimen

We can see that the welded specimen no 4, welded at 950 rpm has a strength of 24.86 N/mm^2 which is more than the unwelded specimens' tensile strength of 24.62 N/mm^2. Therefore we can conclude that a successful weld has occurred at 950rpm.

IV.CONCLUSION

The experimental results indicated that the maximum tensile strength of the joints, which is about 75% that of the base plate, was obtained with a tool rotational speed of 950 rpm. In general it was found that higher rotational speed resulted in higher tensile strength.This is due to the high local temperature achieved at higher spindle speeds leading to the formation of a large quantity of molten material leading to an efficient joint. Also from the bend test we conclude that the bend results obtained from welded specimen is close as that of parental metal.

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