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# Experimental Investigation on Friction Stir Welding of HDPE reinforced with Graphite and Al and Taguchi Based Optimization

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**Abstract.** The extensive application of thermo plastic polymers in different aspects of industries has motivated researchers and companies to improve upgrade the informing, joining and assembling processes to overcome their limitations.Light weight thermoplastics are the most prominent concerns of manufacturers due to their high performance characteristics in the current trend. Weld strength and weld quality are the performance measures of the thermoplastic materials, and determining the optimum weld parameters is the major research problem. This paper presents the optimization of weld parameters required for friction stir welding (FSW) of Graphite and aluminum reinforced in high density polyethylene. The improved mechanical properties of these composites are the resultant effects of the optimum process parameters like welding speed, rotational speed, tilt angle, time and percentage of reinforcement; hence it is very essential to determine them and to study their influence on composites weld joint. The experimental analysis was carried out for three levels in each and different combinations of weld parameters in order to measure the tensile strength and hardness. The optimum set of nine experiments was designed based on L9 Taguchi's design. The elicited test results convey that rotation speed of the tool is the most influential weld parameter for tensile strength and hardness response of FSW butt joint.Maximum weld strength is 66.66 % of the base material and hardness of 2.03 at the weld portion is obtained. The analysis reveals that the added Graphite and aluminum particles enhances the ductility and brittle characteristics to base HDPE sheet causing improved weld strength and in turn ensures the weld quality.
**Keywords:** Friction stir welding; high density polyethylene sheet; Taguchi; weld strength, weld quality.

## 1 Introduction

The application of thermoplastics in many engineering field is increasing due to their intensification in found high specific strength, good corrosion resistance, excellent design freedom and processing ability, polymers and polymer matrix composites have the prospectiveto reduce costs and improve production efficiency with low environmental impact in aerospace, automobile and electronic devices [1].Accordingly, effortshave been made to develop new joining methods for similar anddissimilar polymers [2].Polyethylene is the most significant and adaptable one of commercial thermoplastics. Moreover, polyethylene is utilized in an extensive usage in industrial applications because of its natural structure which can be easily transformed in many different forms. Polyethylene generally needs joining process for the larger and complex parts, though it offers a high intensity of design freedom and processing ability [3]. Welding is the most significant method to join the similar or dissimilar parts without losing the characteristics of the parent material. The welding of plastic materials can be separated into two basic types depends up on the heat generation mechanism, first, heat generation due to mechanical movement (e.g., ultrasonic welding, friction welding, and vibration welding etc.), second, heat generation due to external arrangement (e.g. resistive, hot gas , hot plate and implant welding etc.) [4];The major steps involved in welding of thermoplastics are 1.heating the weld surfaces to a molten state, 2.Bond formation by the application of pressure, 3.Holding the pressure until hardening. All of these three steps provide a great advantage since they are performed at the same time as friction stir welding. Friction stir welding (FSW), is a solid-state welding method invented in 1991 (British TWI), which consists of a cylindrical shoulder and a pin on its crest serves the purpose of heat development and then joining is performed with the pressure exert by the shoulder [4]. In contrast with the traditional welding methods, FSW does not necessitate protective gas, additional wiring, and personal protective measures and it is an eco-friendly process too. Moreover friction stir welding can effectively overcome some drawbacks like porosity formation, gas cavities, and inclusions, etc. which are observed in normal the welding process. plastic materials like low density polyethylene (LDPE) and high density polyethylene (HDPE), polypropylene (PP), nylon, polycarbonate, and acrylonitrile butadiene styrene (ABS) have been studied in the process of joining [1-4, 15–20]. Hence from the various investigations it is evidenced that friction stir welding can be used for welding of unfilled thermoplastic by modifying the process parameters such as rotational speed, welding speed, tilt angle, pin diameter or shape which will have significant effects on the performance of the welded joint. Iftikhar et al. [14], describes that friction stir welding and friction stir spot welding is the suitable methods for welding thermoplastic and thermoplastic composites.

Panneerselvam et al. [15] used polypropylene (PP) sheet to investigate the effect of tool pin profiles, identified that threaded pin profile produces less amount of force and square, triangular & grooved with square pin profile produced defect free welds. Abdulkadhumet al. [22] investigation on high density polyethylene, reinforced with strips of polypropylene reveals that the extraordinary potential to create imperfection – free joints and initiate a high – quality weldment of high density polyethylene sheet. Payeganesh et al. [24] showed that the pin geometry has significant effect on mechanical properties of polypropylene composite welds such as weld surface appearance and tensile strength.Hajideh et al. [23]study on polypropylene to acrylonitrile butadiene styrene by addition of copper powder to the weld zone shows thatadding the copper powder increased tensile strength and hardness of the welded joint.Theprevious investigations shows that when conventional friction stir welding is applied to metals, composite and polymers, it is very difficult to achieve to high quality welded joints due to low meltingtemperature and low thermal conductivity of these materials[21-25].The hardness of welded polymers in the FSW diminishes because of the part of the way finished direction of its sub-atomic chains which is the resultant impact by the blending, combination, and fast cooling in exceptionally less range.Azarsaet al. [25] attempted to develop an efficient method for producing of metal – polymer composites and he identified that surface quality microstructure, ultimate tensile strength and the modulus of elasticity was identified. The literature works exhibit that there are very few publications related to friction stir welding applications of high-density polyethylene (HDPE) especially with ceramics and non – ferrous composites. Hence this study attempts to investigate the effect of weld parameters on mechanical properties of HDPE sheets by using the friction stir welding process. Taguchi based design of experiments is the sophisticated optimization procedure to avoid a large number of experiments, which were too complex, energy-consuming, time-consuming, and uneconomical.Taguchi method uses a special set of arrays called orthogonal arrays to determine the minimal number of experiments to be performed based on the number of parameters and their levels [29].Emamian, S et. al[30] reviewed the tool pin profiles and says that square and conical and cylindrical models will provides the sound joints. The effect of conical threaded profile has to be considered as a significant improvement of stirring process. In this study to examine the characteristics and composition of the reinforcement of Graphite, Al particles in HDPE welded joint, finally finding the optimum set of weld parameters with reference to the weld strength and hardness of the weld joint.The rest of this paper contains three segments to communicate the subtleties of the exploration work in a more straightforward and sharp manner.Segment 2 clarifies the materials and strategies continued in the current work to complete the experimentation and examination, results are introduced in Section 3 with an extreme investigation identified with targets, and the ends drawn out from the outcome examination are expressed under Section 4 with scope for future work finally.

## 2 Materials and methods

In this work the commercial HDPE sheets of 6mm thick are welded to frame a butt joint by friction stir welding process, the schematic outline of the FSW process is displayed in Fig1. The actual properties of chose HDPE sheets are given in Table1.

For the compelling mixing of composites, a cone shaped profile FSW tool is utilized for the examination which has been machined from H13 tool steel having a shoulder dia of 22mm, pin dia 3-6mm, and pin length 4.5 mm as displayed in fig.2 with its cross-sectional view to the side.

The HDPE sheet was butt welded utilizing HMT FN2 vertical processing machine keeping zero-hole as displayed in Fig. 3. Various blends of Al and Gr partials are supported in – between the joining line (notched segment) and pin face at the welded joint. The device was gone along the line of joining to support the Al and Graphite partials into HDPE sheets.

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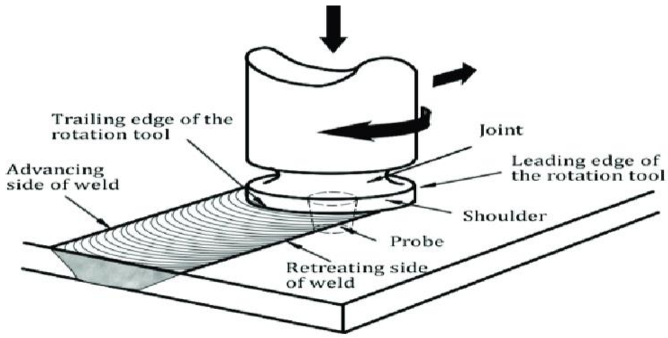
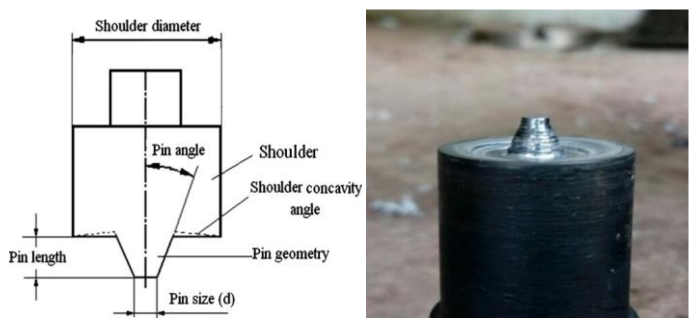



**Fig.1.**Typical Butt-joint welding methodology by a turning shoulder.

**Table 1.** Physical properties of HDPE.

| Molecular weight (Grams) | Density (g/cc) | Young's Modulus ($N/mm^2$) | Melting Temperature ($^oC$) | Thermal Conductivity (W/m-K) | Softening Temperature ($^oC$) | Ultimate Tensile Strength (MPa) | Hardness (HA) |
|---|---|---|---|---|---|---|---|
| 28.0 | 0.930-0.965 | 1035 | 135 | 0.40-0.47 | 112-130 | 26-33 | 17.46 |

A Conical profile FSW device is utilized for the examination has been machined from H13 apparatus steel having a shoulder measurement of 22mm, pin width 3 to 6mm, and pin length 4.5mm is displayed in Fig. 2 with its cross-sectional view to the side.




(a) (b)

Fig 2. (a)Cross-sectional view and (b) Conical pin tool used in friction stir welding.

**Fig 3.** Experimental setup for FSW.

The HDPE sheet was butt-welded utilizing a HMT FN2 Vertical Milling Machine from the start the examples were cut in a necessary shape by utilizing a cutting machine and they were fixed on the apparatus keeping zero holes. The bolts were fixed appropriately and the bed was fixed is displayed in Fig. 3. Various blends of Al and Graphite powders are put between the joining line (notched part) and pin face at the joint. The tool was traversed along that line of joining in order to reinforce the Al and Graphite powders into HDPE sheets.

**Table 2.**Levels in weld parameters.

| Weld parameters | Range | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Tool rotational speed (N) in rpm | 900-550 | 900 | 750 | 550 |
| Welding speed (S) in mm/min | 20-40 | 20 | 30 | 40 |
| Tool Tilt Angle (TA) in | $0^0 – 2^0$ | $0^0$ | $1^0$ | $2^0$ |

| | | | | |
|---|---|---|---|---|
| degrees | | | | |
| Compositions in % | 50-100 | HDPE(Al) | HDPE(Al+Graphite) | HDPE( Graphite) |

## 3 Experimental Method

### *3.1 input parameters*

The key info factors of the exploratory strategy comprise of three levels taken arbitrarily inside the passable reach, recognized to be appropriate for compelling execution [26]. Each chose welding boundary like Tool Rotational Speed (N), Welding Speed(S), Tool Tilt Angle (TA), and level of creation and were displayed in Table 2.

### *3. 2 Taguchi's Experimental Design*

Taguchi L9 orthogonal array is chosen to perform an optimum set of investigations based on the process parameters [23, 26]. The design of the experimental sets as indicated by the L9 orthogonal array for the four welding input parameters are displayed in Table 3.

**Table 3.** Design of Experiments using Taguchi L9 orthogonal array.

| S. No | Rotational speed (rpm) | Weld speed (mm/min) | Tilt angle (degrees) | Compositions (%) |
|---|---|---|---|---|
| 1 | 900 | 40 | 2 | Al |
| 2 | 900 | 30 | 1 | Al+Gr |
| 3 | 900 | 20 | 0 | Gr |
| 4 | 750 | 40 | 1 | Gr |
| 5 | 750 | 30 | 0 | Al |
| 6 | 750 | 20 | 2 | Al+Gr |
| 7 | 550 | 40 | 0 | Al+Gr |
| 8 | 550 | 30 | 2 | Gr |
| 9 | 550 | 20 | 1 | Al |

**Table 4.**Tensile test results and S/N ratio values.

| Exp.No | Rotational speed (rpm) | Weld speed (mm/min) | Tilt angle (degrees) | Compositions (%) | Ultimate Tensile Strength (Mpa) |
|---|---|---|---|---|---|
| 1 | 900 | 20 | 0 | HDPE(Al) | 22.240 |
| 2 | 900 | 30 | 1 | HDPE (Al+Gr) | 21.245 |
| 3 | 900 | 40 | 2 | HDPE (Gr) | 20.876 |
| 4 | 750 | 20 | 1 | HDPE (Gr) | 21.834 |
| 5 | 750 | 30 | 2 | HDPE (Al) | 18.984 |
| 6 | 750 | 40 | 0 | HDPE (Al+Gr) | 12.39 |
| 7 | 550 | 20 | 2 | HDPE (Al+Gr) | 15.94 |
| 8 | 550 | 30 | 0 | HDPE (Gr) | 9.71 |
| 9 | 550 | 40 | 1 | HDPE (Al) | 17.96 |

The terms 'S-signal' addresses its value of it, the S/N ratio (η) can be determined as the result of - 10 and the normal log of mean square deviation (MSD). For the butt joint, both tensile strength and hardness are reasonable to give the larger the–better trademark [29]. MSD for larger – the–better optimal characteristic is expressed as:

$$\text{MSD} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{T_i^2} \tag{1}$$

Where n is the quantity of tests and Ti is the value of tensile or hardness test. The S/N proportion of experimental results for the weld strength and hardness are addressed in tables 4 and 6.

In this work, nine different welding parameter combinations were utilized to complete the experimentation, thusly the effect of each welding boundary on the weld strength can't be obviously perceived from the experimental results. Along these lines, Minitab software design was utilized to clarify the welding parameters like strength and hardness [30], and for more detail analysis obtained graphs from software were used.

# 4 Results and Discussion

## 4.1 Tensile Test

The test results for tracking down the tensile strength of the weld samples are displayed in the table 4,and it tends to be observed that a maximum tensile strength of 22.876MPa was acquired at rotational speed 900 rpm, weld speed 20 mm/min, tilt angle $0^0$and HDPE (with Gr).The noticed ultimate strength weld sample exhibits about 76.48 % of strength of base material. A comparative perception was made by S R Babu and S. R. K. Hudgikar on welded polyethylene sheet and obtained joint 74.67% of base material [13]. Specimen preparation for tensile test was shown in Fig 4.

Composites have more matrix aggregation at the low substance of graphite. At higher substance of graphite, because of its exceptionally permeable construction and high surface region, the low substance of polymeric matrix is insufficient to infiltrate in graphite and, thus, accumulation of graphite in composites. Notwithstanding, at a lower content of bigger graphite particles, the properties of composites are overwhelmed by the matrix contents.

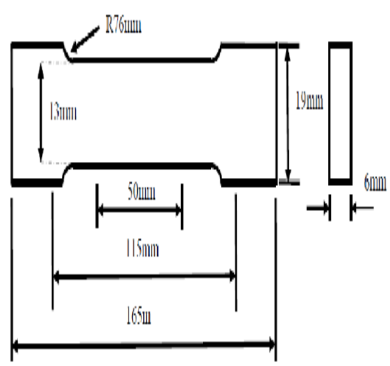



**Fig 4.** Sample preparation for tensile test Dimensional view [17].

The Taguchi S/N ratio analysis is present in the Table 5, considering the main effects of weld parameters on weld strength of the joint. The table shows the most ranked tool rotational speed as the most influencing weld parameter on weld strength and tilt angle as the following significant parameter.

### *4.2 Effect of weld Parameters on Tensile Strength*

Taguchi's S/N ratio analysis gives the main effects plots which are displayed in Fig: 5 in addition to the contour plots, presenting the influence of weld parameters on joint strength. Plots shows that tool rotational speed and tool tilt angle are the most effecting weld parameters on weld strength. As the heat generation is majorly governed by the rotational speed, raise in the rotational speed from 550 rpm to 900 rpm causes to produce more warmth for twisting of the thermoplastic material and to well blend in with Al and Graphite particles.High temperatures at weld zone are attractive for the increased rates of the material mellowing and liquidity, which will ensure the high weld strength at the joint portion. On the other hand at low tool rotational speed the amount of weld strength is less due to low melting and deformation of thermoplastic.

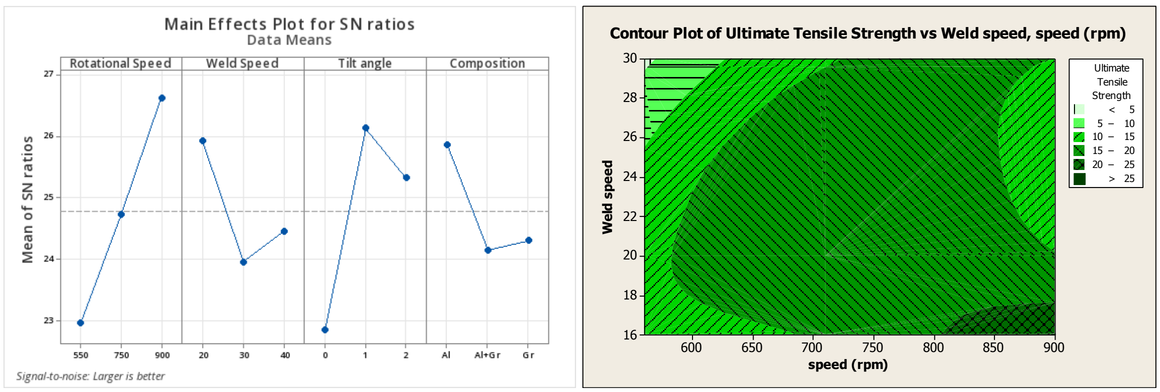



**Fig 5.** Mean S/N ratio and contour plots for tensile strength.

**Table 5.** S/N response table for weld strength.

| S. No. | Weld perimeter | Mean S/N ratio | | | | |
|---|---|---|---|---|---|---|
| | | Level-1 | Level-2 | Level -3 | Max-min. | Rank |
| 1 | Rotational speed | 22.96 | 24.74 | 26.62 | 3.67 | 1 |
| 2 | Weld Speed | 25.93 | 23.95 | 24.45 | 1.97 | 3 |
| 3 | Tilt angle | 22.85 | 26.14 | 25.34 | 3.29 | 2 |
| 4 | Compositions | 25.87 | 24.15 | 24.31 | 1.71 | 4 |

**Table 6.** Hardness test results and S/N ratio values.

| Exp. No | Rotational speed (rpm) | Weld speed (mm/min) | Tilt angle (degrees) | Compositions (%) | Hardness (HA) |
|---|---|---|---|---|---|
| **1** | 900 | 20 | 0 | Al | 28.56 |
| **2** | 900 | 30 | 1 | Al+Gr | 27.45 |
| **3** | 900 | 40 | 2 | Gr | 29.52 |
| **4** | 750 | 20 | 1 | Gr | 30.54 |
| **5** | 750 | 30 | 2 | Al | 25.56 |
| **6** | 750 | 40 | 0 | Al+Gr | 24.25 |
| **7** | 550 | 20 | 2 | Al+Gr | 23.76 |
| **8** | 550 | 30 | 0 | Gr | 26.65 |
| **9** | 550 | 40 | 1 | Al | 23.45 |

### 4.2 Shore D Hardness

Shore D hardness test was conducted along the joint portion, 0.1 mm radius of indenter and the results are presented in the table 6. It was observed that the maximum hardness of 30.54 HA obtained at 750 rpm rotational speed, 20 mm/min weld speed, $1^0$ tilt angle, and HDPE (with Gr), which is more than that of the un-welded base material (17.46 HA).

## *4.4 Effect of Parameters on Hardness*

Table 7 shows the response S/N ratios and the main effects as well as contour plots are displayed in Fig. 6. From these itwas observed that theRotational speed is themajor factor responsible for hardness of the weld joint.The maximum hardness of 30.54 HA observed at weld speed 20 mm/min, rotational speed 750 rpm and tilt angle $1^0$ for Graphite+HDPE composite. The hardness across the Gr -reinforced weld joints is increasing

**Table 7** S/N response table for hardness

| S. No. | Weld parameter | Mean S/N ratio | | | | |
|---|---|---|---|---|---|---|
| | | Level- 1 | Level - 2 | Level - 3 | Max – min. | Rank |
| 1 | Rotational speed | 29.81 | 28.51 | 29.10 | 0.98 | 1 |
| 2 | Weld speed | 28.78 | 28.48 | 28.17 | 0.80 | 3 |
| 3 | Tilt angle | 28.44 | 28.62 | 28.36 | 0.53 | 4 |
| 4 | composition | 28.22 | 27.99 | 29.20 | 0.86 | 2 |

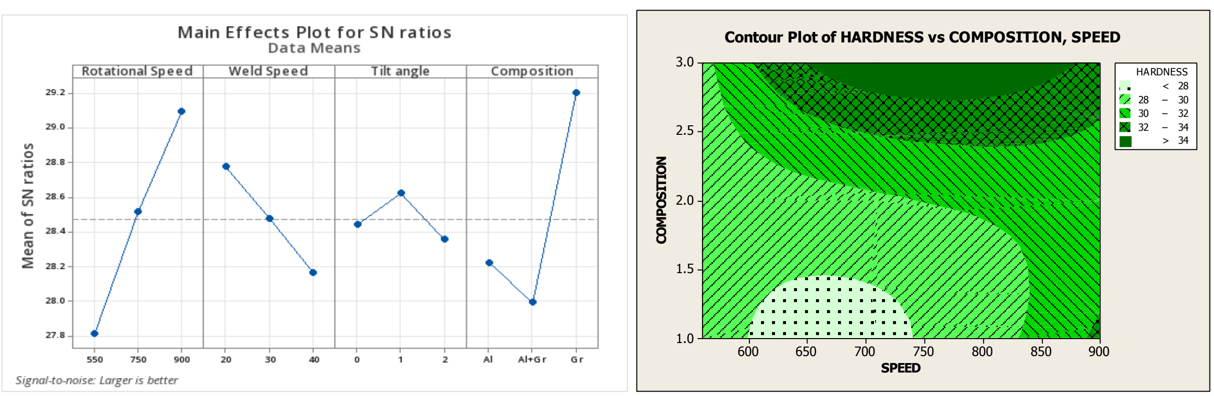



**Fig. 6** Mean S/N ratio and contour plots for hardness

With the increase in weld speed, while that Al composite remains constant at minimum value for the variations of weld parameters. This observation is in accordance with reduction in ductile nature depicted by the Gr + HDPE weld joint and the moderate ductile behavior exhibit by the Al + HDPE weld join.

**5. Conclusions**

Study the effects of Gr and Al particles reinforcement on HDPE in addition to other weld parameters over the weld strength, and hardness of weld joints was the objective of this work in the friction stir welding process. From the experimental analysis, the following conclusions are drawn:

- The rotational speed,composition,weld speed, and tilt angle are the main influencing factors on weld strength and hardness, separately; it impliesthe weld quality is relative to the speeds of the FSW tool at the weld zone.

- The optimum weld parameters for retaining 66.66 % base material weld strength are 900 rpm rotational speed, 20 mm/min traverse speed $0^0$ tilt angle, and HDPE combine with Al particles. The maximum hardness of 35.54 HA at welded portion, obtained at 750 rpm, 20 mm/min, $1^{0,}$ and HDPE combined with Gr parameters set.
- It is observed that the weld quality of joint is also dependent on reinforced partials of Graphite and Al. the effect of improved tensile strength is in accordance with better Al was as hardness is due to the Graphite partials enhancing the contrastingnature to base materials.

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