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Metallurgical Behaviour and Characterization on Polymer Metal with HCHCr Tool by using Friction Stir Welding Adopting L27 Taguchi Technique

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Abstract

Friction stir welding is a technique of combining harmless for the environment because it doesn't use flux or any other shield gas and doesn't produce hazardous gas. To study the FSW process on composite material this work offers an experimental enquiry and optimisation technique. In this investigated how input process operating factors like tool rotational speed, feed rate and depth of cut affect an output parameter like hardness of welded connections and Ultimate Tensile Strength (UTS), Microstructure and metallurgical on the metal. To achieve this L27 Taguchi approach orthogonal array used to optimise design tests on friction stir welding parameters and also HCHCr tool used to improve the good weld ability and to increase the heat input. The experimental setup is run with several combinations of process parameters such as 900, 1000, and 1200 rpm of Tool rotational speed 20 mm, 25 and 30 mm as feed rate by adjusting the depth of cut values of 5.4 mm, 5.6 mm and 5.8 mm respectively. Additionally, utilising the regression analysis equations (ANOVA) used to identify the significant input parameters how it effects for the output metal structure. Finally, by achieved effective evaluation of the metallurgical and microstructure on the nylon 6A metal by various analysis and Testing.

Keywords: *FSW, Metallurgical Testing Unit, Minitab Software, Nylon 6A and its Composite Metal, SEM*

1.0 Introduction

Polymers and Polymer Matrix Composites (PMCs) have the potential to increase production efficiency, decrease costs, and have less of an impact on the environment in electronic, automotive, aerospace devices. Good processing capabilities, large specific strength, and resistance to corrosion and outstanding design freedom are among these advantages for the creation of big and complex parts, combining technology using joining techniques such bonding and fastening is necessary[1]. By altering the mechanical fastening at the bonding area, force concentration easily develops for lowering weld dependability, which accelerates the degradation of lightweight designs. Adhesive bonding, which has a lengthy processing cycle, is mature in comparison. Nevertheless, lowering joint property cannot be accomplished solely by reducing impact resistance, fatigue resistance, and resistance to humidity. Welding, which employs several techniques includes electric resistance welding, hot plate welding, and linear vibration welding FSW, and ultrasonic welding, among others is the finest

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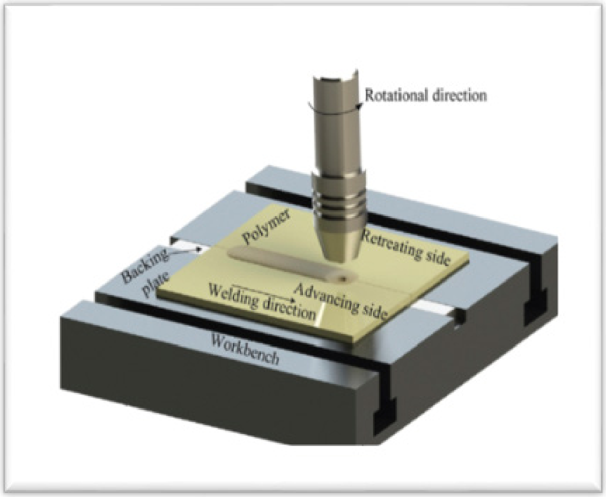

Figure 1. Representational image of Friction Stir welding.

way to connect. These welding techniques consist of three distinct processes: 1st layer of molten material is created to be linked on the surfaces, 2nd upsetting produces the bonding, and 3rd the phase of pressure and cooling of the molten material need to be ensured to avoid voids forming inside the weld zone[2,3]. Spot welding mostly done with ultrasonic welding, although it costs more to buy the equipment and takes longer to set it up. A groove calls for the use of hot gas welding and extrusion techniques to construct the proper union at an excruciatingly slow rate. However, the qualities heavily rely on the operator's skill level. Machine parts cost more because friction welding necessitates a flattened face. Due to its benefits, including its FSW may be able to compensate for the shortcomings of the afore mentioned welding techniques good joint quality, significant plastic deformation, lower temperature, inexpensive machine usage, quick process times. The FSW diagram displayed in Figure 1. During FSW technique, a pin and a shoulder with a unique design are included in the rotational tool[4]. When rotating at a high speed, the work pieces' frictions provide material flow, frictional heat, and the combination of joining materials necessary for joining.

FSW is not a solid-state process since the polymers contain atoms of chain lengths and lack specific melting points in favour of melting ranges[5]. Rather, they are thermoplastic polymers that are distinct from metal. When FSW/P is applied to polymers, certain shorter chains of FSW may melt while larger solid chain. FSW for nylon polymers was applied in the year 1997, but due to its youth, there are few works reports. Several thermoplastic polymer combining tools have been improved. The comprehensive study of the FSW of thermoplastic polymers began in 2005, but particularly in 2009. FSW is responsible for fusing PMCs and thermoplastic polymers together. These polymer composites are created using substances such as polyethylene terephthalate, polycaprolactam (nylon 6A), Polymethyl Methacrylate (PMMA), Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polypropylene (PP), and different grades of Polyethylene (PE). They also include Polyethylene (PE)[6,7]. Using a specifically made tool a conical pin with a concave shoulder and grooves, Raza *et al.* friction stir welded connections using High-density Polyethylene (HDPE) sheet The joints were made with silica, graphite, alumina, and silicon carbide both with and without the ceramic particles (SiC) [8,9]. The relevance of the composite junction made of SiC-HDPE that provides design of tool and the best friction stir welding parameters may be acknowledged in high strain rate applications. Due to the poor welded qualities of the particle's agglomeration noted how difficult it was to disperse particles using conventional methods in metal, polymer matrix, and ceramic composites. The dioxide particles on the area of the aluminium matrix are uniformly dispersed using the two-pass friction stir technique. Huang *et al.* investigated the manufacturing of multifunctional composites, the FSW of thermoplastic polymers and PMCs, and the FSW of dissimilar metals and polymers. Also, the manufacturing of future-related scientific research and engineering, also known as FSW, as well as thermoplastic polymers and PMCs has been established. In the FSW of it was decided whether to use a secondary heating system or polyamide 6 or nitrile butadiene rubber composite. By mechanical testing, the tool setup reliability at various rotational speeds was examined. By using a heating method to produce the welds and significantly develop their mechanical qualities, flaws and inappropriate fusion have been reduced to a minimum. They concluded that with more than 91% of the basic material mass, the highest tensile strength was 61 N/mm^2 to create stable hetero junctions between metals and PMCs and enhance their mechanical properties, two techniques include adhesive bonding and multiscale mechanical interlocking[10]. Whole tensile shear strength of 27 MPa was achieved using adhesive bonding and multiscale mechanical interlocking. FSP-produced UHMW polyethylene composites with nano-hydroxyapatite particles were examined for their Rockwell hardness and impact strength. Here, the processing parameters were shoulder temperature, volume fraction of the strengthening material, tool traverse speed, and spindle speed. Attention must be given while selecting the processing options for the variance analysis (ANOVA) [11]. In the microscopic analysis The reinforcing particles tended to clump together due to the lesser temperature, more tool traverse speeds, and proportion of volume, creating voids and channels that decreased the impact strength and hardness of the produced composite. To understand how welding conditions, affect how successful hybrid joints are in terms of tensile shear strength, it was advised to conduct a trial study project[12]. which discusses the FSW methods for combining several types of thermoplastics, both with and without fibres, using sheets of aluminium alloy. The welding process and material weld ability were taken into account when analysing the instrument geometries. Microstructural analysis also revealed good thermoplastic and aluminium fusion as well as welds free of flaws evaluated thermoplastic polymer-based composite sheets containing 12% continuous carbon fibre. The composite sheets were shaped like buttocks. A contemporary tool constructed of St37 plain carbon steel is employed in this FSW and low-cost turning system[13] the optical microscope images further demonstrated the whole relationship between the materials. Increasing the inlet temperature promotes the growth and development of cavities, which transform into cavities in the tube. Also, the crucial shoulder diameter and other variables that have an impact on link efficiency were also taken into consideration on the basis of Scanning Electron Microscopy (SEM), The rotating speed is increased, which causes the continual grinding of carbon fibres and increases the tensile strength. Glass fibre reinforced Polyamide 6 (PA6) has most recently been subject to the FSW. It is assessed by measuring the weld strength and fibre length distribution at the weld seam. Using the tensile strength as a starting point, the primary consequences of the friction stir joint specimen were examined. Greater touch pressures could disclose a tensile strength that is 50% of the strength of the base material. For large-volume measurements of fibre length, the measuring technique is also used and tested. To investigate the feasibility of welding different polymathic methacrylate and polycarbonate sheets used the FSW method. The effects of heater temperature, rotating speed, and traverse speed on the parameters joints mechanical characteristics were thoroughly examined[14]. As specified as the joint's optimal mechanical qualities, the heater temperature of 120°C, rotation and traverse speeds of 2100 rpm, and 8 mm/min, respectively. The welded junction was produced in the ideal joining state and had greater hardness and strength than polycarbonate (98% equivalent strength). Three distinct pin profiles have been used by the authors of the impacts on square, threaded, and tapered nylon 6 plates should be studied. The material flow was examined using the marker material insert technique. In contrast to metals, a square pin showed the greatest rearward displacement of marker materials, which determined the pin profile's important impact in horizontal displacement. Also, no side showed the forward flow of any pin profiles. On the glass-filled nylon 6 composites, the feasibility of FSW was studied by Kumar *et al.* The FSW process was used to make nylon 6 composites with glass filling based on an injection moulding machine and attach them to H13 tool steel. The mechanical and morphological characteristics of Friction Welding sections of glass-filled nylon 6A composites were examined in a full factorial experiment design using Tool traverse speed (0.2, 0.3, and 0.4 mm/s), tool tilt angle (0, 1, and 2), and TRS (400, 500, and 600 rpm) with constant standoff distance (0.2 mm). ANOVA has also been used to estimate the relevance of the tensile strength and % elongation process factors. Due to PMCs' better qualities, such as their inexpensive cost and improved toughness with great strength/stiffness-to-weight ratio, traditional metals and unfilled polymers have been practically replaced. FSW also developed into one of the crucial weld techniques for thermoplastic polymers[15].

2.0 Selection of Material and Methodology

In this paper, nylon 6A a polymer that can duplicate nylon 6 qualities without infringing on the material's patent is used. It has application to polyamide with semi crystals. Nylon 6A is not a condensation polymer, in contrast to other nylons. Yet by contrasting addition polymers with condensation, ring-opening polymerization creates a distinct instance. Because of their flexibility, high tensile strength, nylon 6A fibres are generally difficult to work with. They have a high level of resistance to acids and alkalis as well as abrasion. Even though it lowers the tensile strength, 2.4% of water may typically be absorbed by the fibres. Additionally, it takes into account the glass transition temperature of 47°C. Nylon 6A can be coloured in a solution method before producing various colour effects because synthetic fibre. Heat resistivity up to 150°C, and melting point up to 215°C, bulk density is 1.14 gm/cc, and tenacity is between 6 and 8.5 gm/den. D3 chromium tool steel, which has excellent wear resistance, contains 12% ledeburite chromium tool steel. Nonetheless, it can be used as blanking dies for paper and plastics, with sheets up to a thickness of 4 mm, and as cutting tools for rotational shear edges, with sheets up to a thickness of 2 mm. The main characteristics of D3 steel include strong wear resistance, 12% chromium tool steel, and 2% HC steel. This D3 steel, which anneals to facilitate easy machining depending on its supply availability, is used to produce dies and tools that have a hardness of 57 to 58 HRC.

2.1 Tensile Strength Test

Tensile tests are used to evaluate the mechanical behaviour of composites and matrix alloys. The gauge lengths of 30 mm and lengths of 13.5 mm were tensile tested using composite materials and matrix alloy. Before necking, when the specimen's cross-section starts to significantly compress, UTS, commonly abbreviated as a material's tensile strength is its capacity to resist the highest amount of stress when being stretched or pulled. Figure 2 shows the ASTM standard specimen for UTS's dimensions.

2.2 Microstructure Hardness

The samples with metallographic structure were extracted from the nylon 6A polymer composite and connected using the FSW process. The Dynamic Recrystallization Zone (DCZ), the Thermomechanical Affected Zone (TMAZ), the Heat Affected Zone (HAZ), and Base Metal (BM) are all being investigated. The cross-sectional surfaces of the welding joints have yielded images of the micro- and macro-structure.

2.3 Experiment Design Using the Taguchi Technique

For the purpose of gathering data and producing precise conclusions, this paper used the DoE technique. Using MINITAB 19 software to findings of the orthogonal array (L27) were evaluated. Three process variables were chosen: depth of cut (mm), TRS (rpm) and feed rate (mm/min), and as the FSW's output replies, hardness and UTS are also assessed joint and the work piece is joined using the HCHCr tool. The input process parameter values and levels are included in Table 1 for convenience.

Table 1. Input Process Parameter

Process Parameters	Level 1	Level 2	Level 3
Tool Rotational Speed (rpm)	900	1000	1200
Feed Rate (mm/min)	20	25	30
Depth of cut (mm)	5.4	5.6	5.8

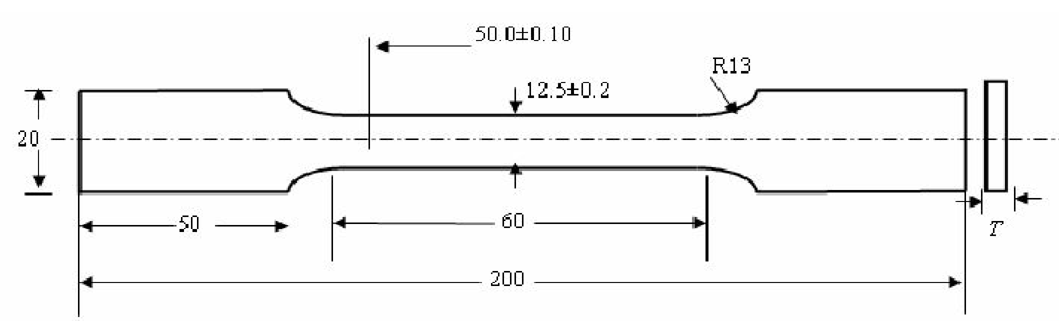

Figure 2. Standard Specimen for Ultimate Tensile strength.

2.4 L27 Taguchi Technique

The Taguchi strategy which was examined to identify the variables under your control that have the best FSW response characteristics, is the resilient design approach that is most frequently used in machining operations. To minimise the impact of while creating the tests, there were uncontrollable components, the Taguchi approach is applied in experimental designs.

Table 2. Taguchi L27 orthogonal array

Sl. No.	TRS (rpm)	Feed Rate (mm/min)	Depth of Cut (mm)
1	900	20	5.4
2	900	20	5.6
3	900	20	5.8
4	900	25	5.4
5	900	25	5.6
6	900	25	5.8
7	900	30	5.4
8	900	30	5.6
9	900	30	5.8
10	1000	20	5.4
11	1000	20	5.6
12	1000	20	5.8
13	1000	25	5.4
14	1000	25	5.6
15	1000	25	5.8
16	1000	30	5.4
17	1000	30	5.6
18	1000	30	5.8
19	1200	20	5.4
20	1200	20	5.6
21	1200	20	5.8
22	1200	25	5.4
23	1200	25	5.6
24	1200	25	5.8
25	1200	30	5.4
26	1200	30	5.6
27	1200	30	5.8

To reduce the uncontrolled components in the trials, a L27 orthogonal Taguchi array, as shown in Table 2, is chosen due to the predictable distribution of interactions between the input components and the facts. As soon as the trials were finished, the Taguchi experimental design was assessed in order to collect by converting the data to a signal-to-noise (S/N) ratio. The intended quality value used to determine and evaluate the standard ratio values in a variety of methods, with nominal greater being better.

3.0 Experimental Research

This section explains the experimental study that was conducted to confirm Figure 3, illustrates the mechanical characteristics of Friction Stir Welding on nylon 6A, often referred to as polycaprolactam material. UTS and hardness are used in this instance as the parameters that will be examined both before and after the FSW process. For the task, a vertical milling machine with automatic feeding is used, and the feeds and TRS are set up taking into account the profile of a tapered threaded tool as illustrated in Figure 4 and figure shows an FSW machine setup that satisfies the following conditions:

1. Motor capacity: 1.5 kw
2. Rotation of Speed: 4000 rpm
3. Feed rate: 2000 mm/min
4. Maker: Bhavya Machine Tools 430x260x400 (Worktable Size)

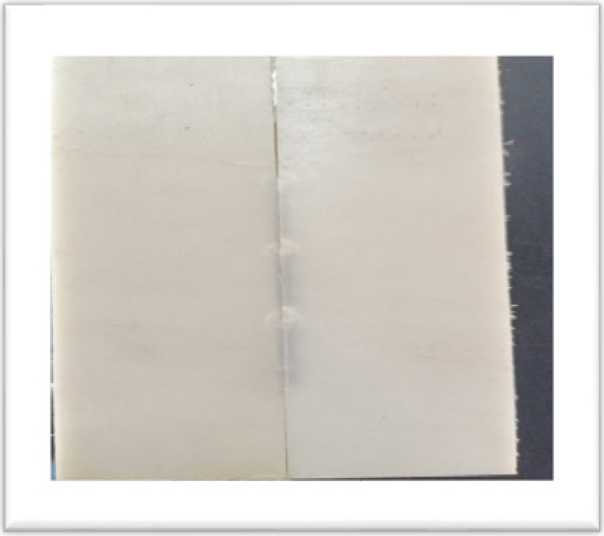

Figure 3. Nylon 6 work piece.

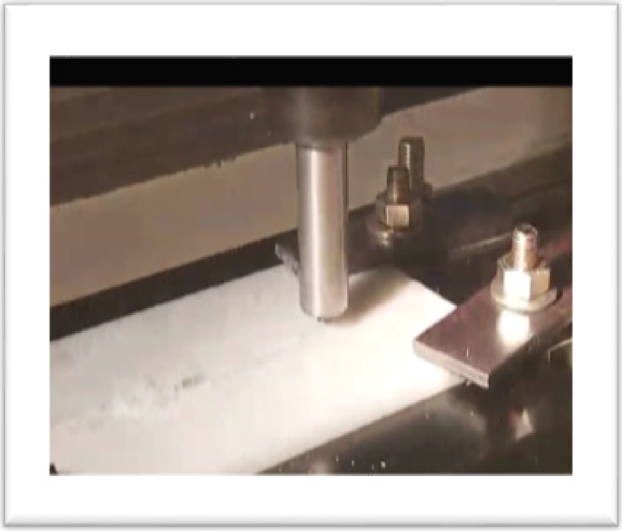

Figure 4. Threaded Taper profile.

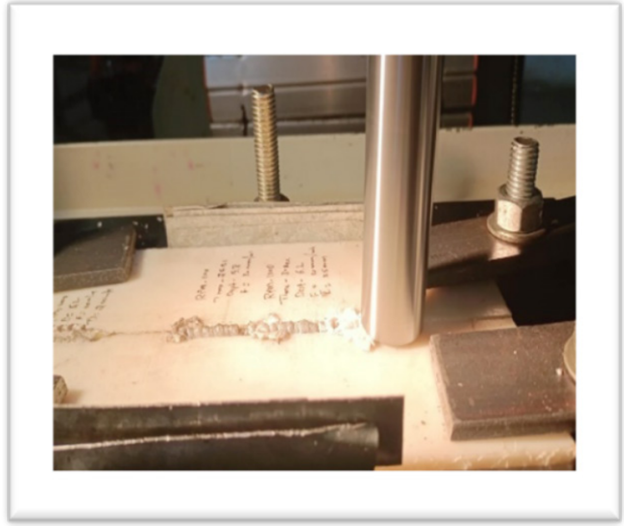

Figure 6. Work Piece Clamping.

3.1 Tool Used

Due to its adaptability, distinct hardness, capacity to maintain high temperature cutting edge, abrasion and deformation resistance steel tool, which is a combination of different alloy and carbon steels, is ideal for use as tools. Tool steels can thus be used to shape other materials. Six categories of tool steels are available, includes stress resistance, high speed, and hot work, cold-work, water-hardening, and specialty. The group decision is made taking into consideration the requirements for tensile strength, stress absorption, necessary surface hardness, and operating temperature, and cost. The following specifications for HCHCr which is used in this project as a tool material, are provided.

1. length of the tool: 100 mm
2. Tip of the Tool diameter: 6 mm
3. Pin length: 5.8 mm
4. The diameter tool shoulder: 22 mm

Figure 5. FSW Machine.

3.2 Process

The nylon plates are measured in millimetres, and the desired size is 100x50x6 then obtained by shearing the plates. Thereafter, as shown in Figure 5, both nylon plates are secured to the bed of the machine. As indicated in Figure 6, a centre tool bit is given the plunge depth at the point where the plates intersect, and a hole is produced to allow the tool to be made into the FSW to traverse the plates 6. Once the hole has been made and pressure has been applied to the plates using the tool shoulder, the tool passes over the intersection of the two plates. The tool advances to the other side of the weld in accordance with the automatic feeds. After inserting the tool, sometime is given for friction to build up before the material is started heated to the point where the plates are red-hot. Nonetheless, the period is seen as lasting between 5-8 seconds and is known as the indentation time. The plates are regarded as having been friction stir welded once the tool has crossed over shown in Figure 8.

4. Results and Discussions

The outcomes of using the FSW method with nylon 6A work piece and tool with a profile of tool profile taper threaded are described in this section. In this case, the input process parameters are the TRS (rpm), feed rate (mm/min), and depth of cut (mm), while the output parameters are the UTS and hardness, which indicates that the ultimate strength of the weld is determined using these UTS and hardness values. The input values were chosen according to the maxim "the bigger, the better" approach to achieve largest tensile strength. Table 3 includes modifications in the process parameters, such as TRS (rpm), feed rate (mm/min), and depth of cut (mm), together with experimentally acquired values, such as UTS and hardness.

Table 3. Obtained Experiment Results UTS & Hardness

Sl. No.	Tool Rotation Speed (rpm)	Feed Rate (mm/min)	Depth of Cut	Ultimate Tensile Strength (N/mm^2)	Hardness
1	900	20	5.4	28.14	90.17
2	900	20	5.6	29.34	91.87
3	900	20	5.8	32.23	93.23
4	900	25	5.4	29.67	90.23
5	900	25	5.6	32.34	92.34
6	900	25	5.8	34.34	94.1
7	900	30	5.4	30.23	90.2
8	900	30	5.6	33.32	91.24
9	900	30	5.8	34.98	93.23
10	1000	20	5.4	35.14	93.12
11	1000	20	5.6	37.34	95.2
12	1000	20	5.8	38.23	96.2
13	1000	25	5.4	37.67	93.98
14	1000	25	5.6	38.34	94.21
15	1000	25	5.8	39.34	95.18
16	1000	30	5.4	40.23	92.14
17	1000	30	5.6	41.32	94.18
18	1000	30	5.8	43.98	95.12
19	1200	20	5.4	45.14	96.23
20	1200	20	5.6	47.34	97.87
21	1200	20	5.8	48.23	103.23
22	1200	25	5.4	49.67	96.56
23	1200	25	5.6	50.34	105.45
24	1200	25	5.8	51.34	107.23
25	1200	30	5.4	53.23	98.23
26	1200	30	5.6	54.32	106.67
27	1200	30	5.8	54.98	109.34

Figure 7. Weld Zone on Composite polymer.

4.1 Comparison of Variance (ANOVA)

To determine how significant these connections are, the Fisher test is performed. The influence of the input operational procedure variables on the output responsive parameters, or mechanical qualities of welded joints, is assessed using ANOVA. The maximum yield stress for tensile materials is examined in this article. To determine the influence of each control factor on response, an estimated ANOVA is needed. The practically findings are evaluated using the ANOVA approach, which finds the input parameter contributions on UTS and hardness, to determine which design specification have a substantial impact on the feature. The experimental findings are evaluated using the ANOVA approach, which can determine how input factors affect UTS and hardness and pinpoint their effects, in order to determine which design parameters have a major impact on the characteristic. Using ANOVA and a 90% confidence interval for the experimental inquiry, it is possible to identify process variables whose variability in the design space influences output response measurements. The relevance of the component is taken into account if the calculated probability value is 10% or below. After an ANOVA, the results of are presented in Table 4 along with their significance for the output response metrics of UTS and hardness, respectively.

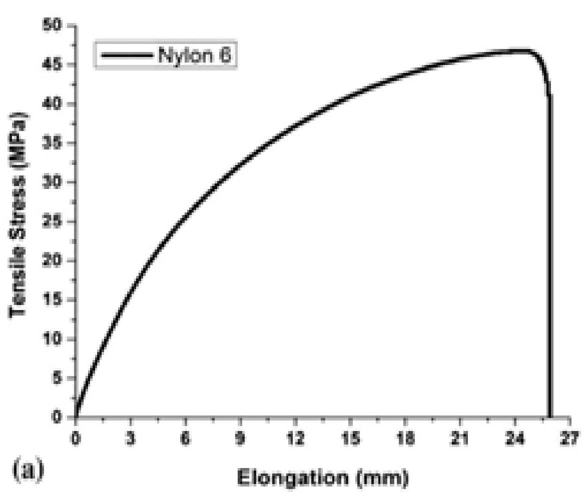

Figure 8. Tensile Strength Vs Elongation.

Figure 8 shows Tensile Strength Vs Elongation in this graph shows the % of elongation its increases the tensile strength also will increase at some certain stage once it's reached the maximum yield point of nylon 6 the strength of the nylon 6 keep on decreases.

Table 4. Key variables and associated P Values for the process of FSW

Models	P Values	
Factors	UTS	Hardness
A	0.027	0.004
B	0.087	0.005
C	0.06	0.008
A^2	0.08	0.047
B^2	0.057	0.004
C^2	0.05	0.004
AB	0.01	0.08
AC	0.044	0.006
BC	Insign	0.020
AC^2	Insign	Insign
BC^2	0.095	Insign

4.2 Regression Analysis

Regression analysis is carried out following the weld joining procedure using the findings of the collected data. The MINITAB software is used to derive the linear equations that are pertinent to the dependant and independent variables, and these are the regression equations:

UTS=123.0-0.0225A-3.90B-20.2C + 0.000004A2+ 0.0449B2+ 5.6C2+0.000134AB+ 0.0056A+0.243BC-0.00197AC2-.064BC2 **Equ. 1**

Hardness = 115.2+0.0372A-2.383B-18.5C-0.000016A2+ 0.03313B2+4.16C2- .000080AB+ 0.01079AC+ 0.010BC- 0.00203AC2-0.008BC2 **Equ.2**

The effectiveness of equation (1) for forecasting the variance inside the design space may be realised according to the values listed of, R2 Adj R2 and Pred R2 in Table 5. After using ANOVA, the developed model equations were applied to all output responses based on the findings analysis to assess the range of the design space's variation.

Regression analysis of hardness and impact strength results shows good co-relationship as shown in Table 5 Multiple R and R square values are found to be 0.98 and 0.94, respectively, while the standard error found is 0.048 which shows a good co-relationship.

Table 5. Residual for all the performance measures

	UTS	Hardness
R_2	0.9892	0.9986
Adj-R_2	0.9677	0.9794
Pred R_2	0.9487	0.9574

Taguchi designs that reduce Variability in a process or a product while reducing the influence of uncontrolled elements are measured for robustness in order to find the control factors (noise factors). Controllable parameters are design parameters, and process parameters are those that can be changed. Noise variables cannot be controlled while a product is being used or produced, but they can be controlled while an experiment is being conducted. The noise levels are calculated using a Taguchi-designed method for the occurrence of force variability. To make the process or product resilient or resistant to Adaptation to noise sources, the settings of the ideal control factor are identified. Higher values of the S/N ratio, which lessen the impact of the noise components, are indicative of control factor settings. The S/N ratio is used to quantify the degree to which the response deviates from the goal or nominal value under various noise situations. Three quality characteristics Better is larger, better is nominal, and smaller is better are developed by Taguchi and are based on the experimental purpose. Several S/N ratios are used.

4.3 Process Variables Affecting UTS Impact

Table 6 provides the response statistics for UTS's S/N ratios. Figure 9 displays the operation process input variables, including the feed rate, depth of cut, and S/N ratio on UTS, as well as the response line's divergence from the horizontal line. This illustrates how these operating process parameters have a significant impact on UTS as well as how they have a high impact on the performance measure. When using an HCHCr tool to machine nylon 6A material for UTS, the most crucial factors are the depth of cut and pace input operating process factors, while the feed rate is the least important.

Table 6. Responses for S/N Curve ratio of UTS

Level	TRS	Feed Rate	Depth of Cut
1	32.24	32.89	31.34
2	30.53	29.6	30.36
3	31.33	32.2	32.54
Delta	4.69	2.66	1.20
Rank	1	2	3

4.4 Effect on Hardness

Table 7 displays the response to S/N ratios of hardness. Input operational process factors for the S/N ratio, such as TRS, feed rate, and depth of cut, are shown in Figure 10. The divergence of the response line from the horizontal line illustrates these operational procedures characteristics have a considerable impact on both the

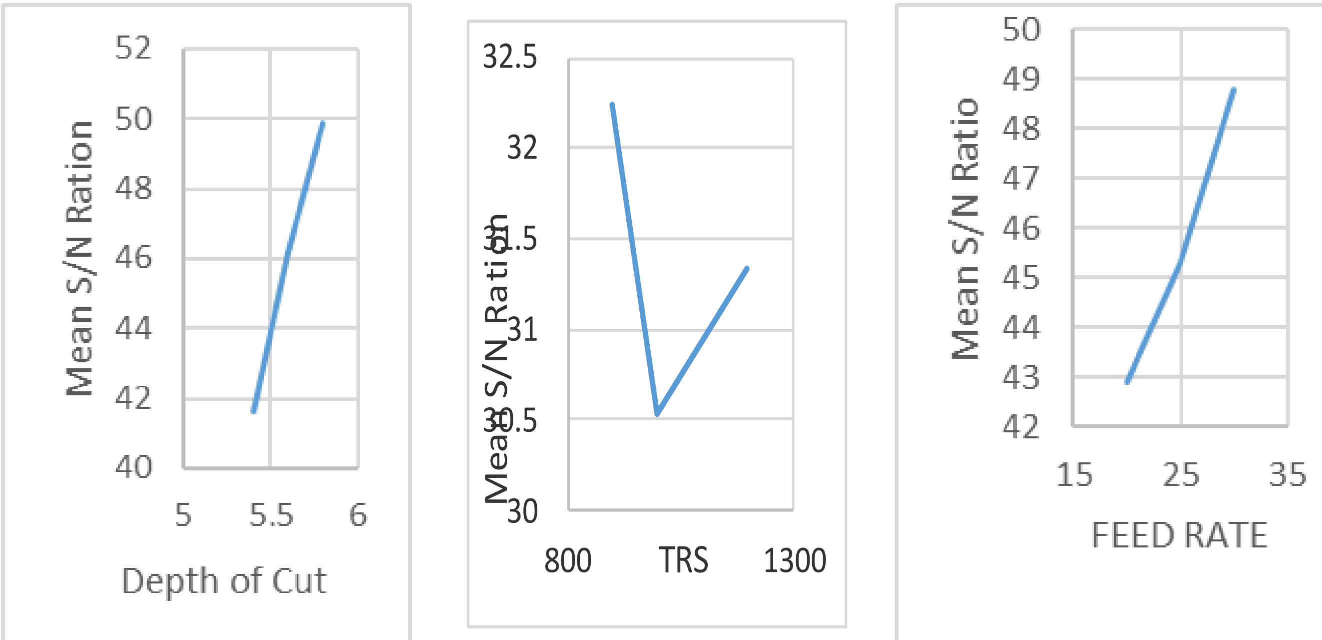

Figure 9. Effect Plot For S/N Ratio of Ultimate Test.

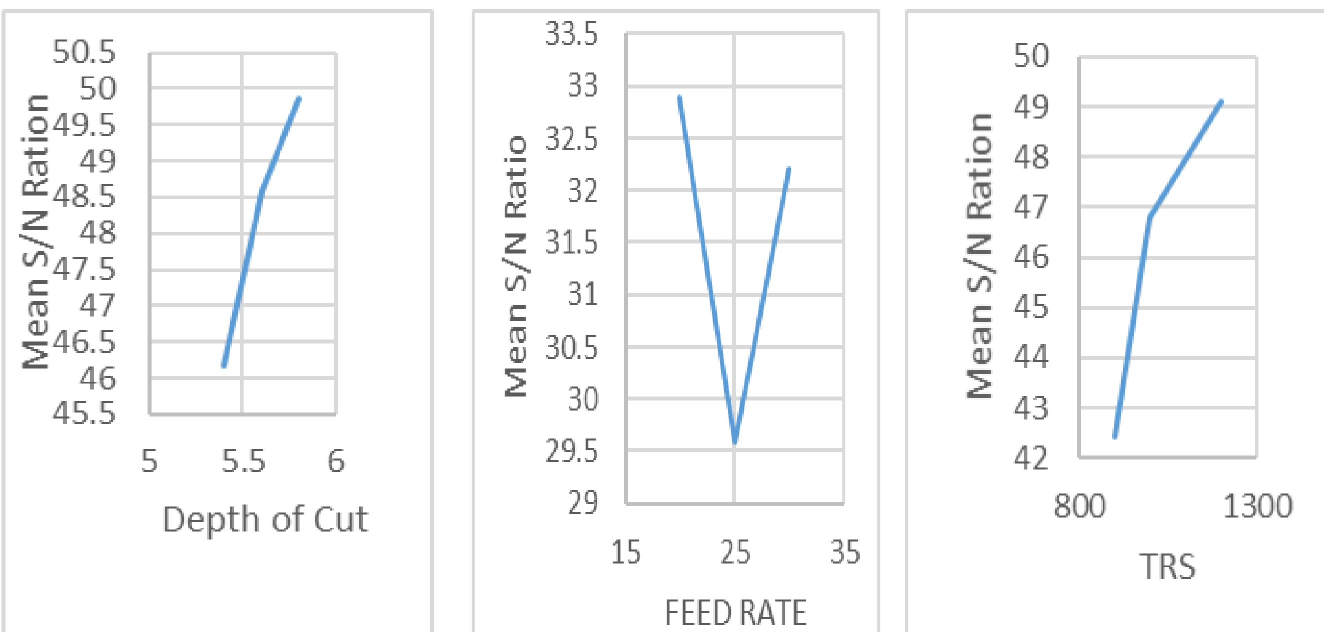

Figure 10. Main effect plot for S/N ratio of hardness.

performance measure and hardness. The three most important input process parameters for using the HCHCr tool to machine nylon 6A material for UTS in FSW are TRS, depth of cut, and feed rate.

The hardness of nylon 6 plate in the welded zone is keep in increasing due to proper mixture of materials in the nugget portion. It depends on the rpm of the tool, depth of cut and type of tools used hence by seeing the results in Table no 3 1200 rpm and 5.8 depth of cut it's clearly shows the major hardness is covered compared to all other parameters.

Table 7. Responses for S/N ratio of hardness

Level	TRS	Feed Rate	Depth of Cut
1	42.41	42.90	41.59
2	46.81	45.3	46.18
3	49.12	48.8	49.87
Delta	3.21	1.81	0.92
Rank	1	2	3

4.5 Analysis of Microstructures

The samples with metallographic structure are taken into consideration from the nylon 6A polymer composite, and these are afterwards combined with the FSW and then thoroughly inspected. As shown in Figure 11, FSW joints comprise the Bases Metal (BM), Heat Affected Zone (HAZ), nugget zone, and Thermomechanical Affected Zone (TMAZ) structures. Both the micro and macro sizes of these formations are investigated. Figure 12, 13 & 14 shows micro- and macro-structure-based pictures that were acquired from the cross-sectional surfaces of the welding joints.

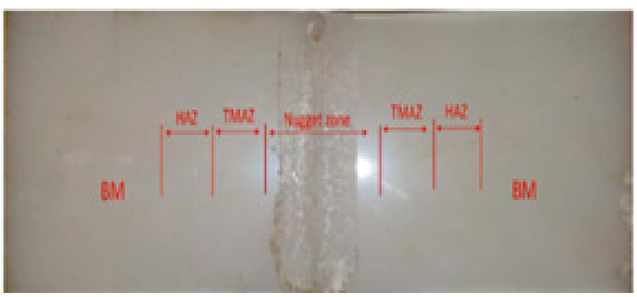

Figure 11. Generated zones in the FSW methods weld cutaway.

4.6 SEM Analysis Photos

Structures have been altered in accordance with the TRS and feed rate. If the microstructure of the welded sample was investigated at a speed of 1200 rpm and a feed rate as high as 30 mm/min, the connecting zones' large gaps were visible. If the microstructure of the welded sample was evaluated at a 900 rpm TRS and a 20 mm/min feed

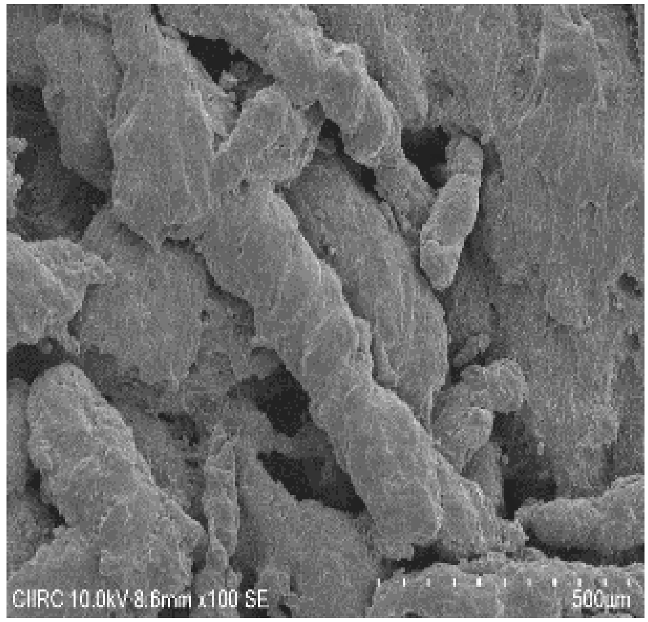

Figure 12. SEM Analysis of 900 RPM.

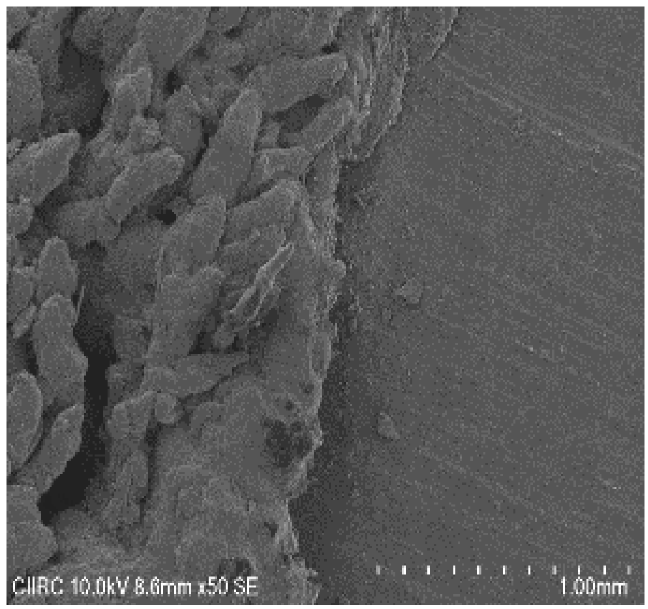

Figure 13. SEM Analysis of 1000 RPM.

rate, there was less porosity at the connecting zones. After that, the material is extruded to improve joining. Zones and gaps at the base of the nugget zone are visible in the welding centre. By raising the feed rate and TRS values, the gaps' sizes and numbers grow in the welded joints. The increment in the flaws' size is anticipated using the unit area's temperature dropping.

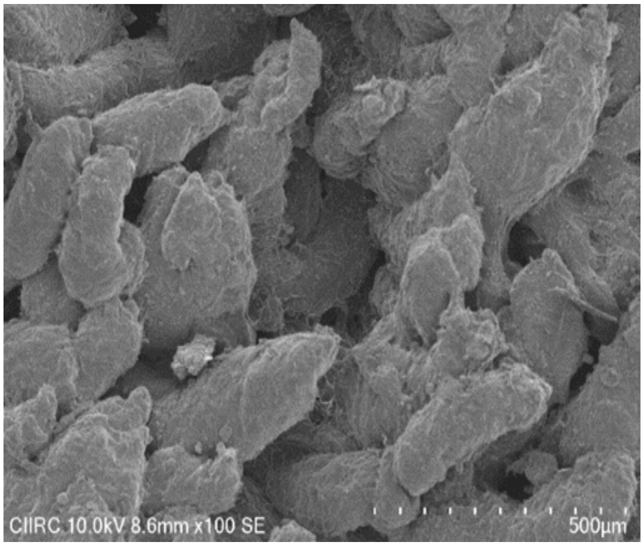

Figure 14. SEM Analysis of 1200 RPM.

5.0 Conclusions

In this work it was suggested that the FSW technique to be investigated experimentally on polymer nylon 6A material utilising tool with a taper threaded tool profile made of HCHCr and varied depth values. Taguchi's L27 orthogonal array technique is also used to find the best process parameters. Also, an ANOVA using regression equations is carried out to show how input parameters for the operational process affect output indicators such as UTS and hardness. From the obtained experimental and optimal results, the following conclusions were drawn:

1. Taguchi's findings demonstrated that mathematical models can predict FSW parameters with a 95% confidence interval.
2. Feed rate and tool rotation are, respectively, the most and least important FSW factors.
3. When developing the nylon 6A polymer composite's FSW joints UTS, factors including feed and TRS were taken into account.
4. The greatest UTS was achieved using the ideal FSW parameters rate of feed of 30 mm/min, tool depth of cut 5.8 mm, and TRS of 1200 rpm.
5. The metallurgical and microstructure properties are also improved by using this technique.

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