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Research article

Optimization of hot plate welding parameters of glass fibered reinforced Polyamide 6 (PA6 GF15) composite material by Taguchi method

Umut Kocatüfek[a], Çınar Yeni[b], Aydın Ülker[c], Sami Sayer[d], Uğur Özdemir[e]

[a]Graduate School of Natural and Applied Science, Department of Mechanical Engineering, Dokuz Eylul University, Turkey
[b]Department of Mechanical Engineering, Faculty of Engineering, Dokuz Eylul University, Turkey
[c]Graduate School of Natural and Applied Science, Department of Mechanical Engineering, Ege University, Turkey
[d]Department of Plastics Technology, Ege Vocational School, Ege University, Turkey
[e]Department of Mechanical Engineering, Faculty of Technology, Amasya University, Turkey

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Abstract

In this study, the effect of four welding parameters on hot plate welding of polymer composite, polyamide 6 (PA6) with 15 %wt glass fiber reinforcement (PA6 GF15) was investigated. The parameters considered are the plate temperature (PT), heating time (HT), welding displacement (WD), and welding time (WT). Three levels for each parameter were selected. For hot plate welding process of the specimens, L9 orthogonal array was used within the frame of Taguchi experimental design method. The tensile strengths of the joints were examined by using analysis of variances, and optimum welding strength was compared with the results obtained from confirmation run. As a result of the ongoing analysis, it has been observed that in PA6 GF15 polymer composite, 270°C of plate temperature, 1 mm of the welding displacement stroke, and 25s of heating time were the optimum combination suggested by Taguchi method. The welding strength was improved approximately 27% from initial welding parameters.

Keywords: *Hot plate welding, polyamide 6, glass fiber reinforced, Taguchi method*

1. Introduction

1.1. Plastics

The low density of polymer based thermoplastic materials compared to metal based materials enables them to be selected as constructive materials in many industries. Thermoplastic materials are classified as commercial plastics, engineering plastics and high performance plastics. While commercial plastics (PP, PE, PVC, PS) are used in production areas that require low mechanical strength, generally at temperatures below 100°C, engineering plastics (PE, PC, PET) and high-performance plastics (PEK, PES, PSU)

*Corresponding author:
E-mail: aydinulker@hotmail.com
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have come forward as alternatives to metal and non-metal materials for applications requiring high mechanical strength in a wide temperature range. Although the production quantities of engineering plastics are low compared to commercial plastics, their economical values are relatively higher. Polyamide materials, classified within engineering plastics, possess high mechanical strength, sliding, and corrosion resistance. They also may acquire ductility through conditioning [1].

1.2. Identification of PA6 and Glass Fiber Materials

Although PA materials were discovered in the 1930s, they have started to be widely used in industry following the development of screw injections after the 1950s. The worldwide annual production rates of PA raw materials considered among engineering plastics have reached about two million tones [1].

1.2.1. Fiber types and properties

Fiber reinforcement within the matrix material constitutes the basic strength of the composite structure. In addition to their low density, these fibers possess high modulus of elasticity and rigidity as well as resistance to chemical corrosion. Nowadays, the most significant reinforcement materials used in composite structures are continuous fibers. These fibers play an especially important role in the formation of modern composites. Glass fibers are the oldest types of fibers used in industry. Boron, carbon, silicon carbide, and aramid fibers, developed in recent years are mostly used in advanced composite structures. By producing fibers in very small diameters, structural error probabilities have been minimized compared to large mass structures. Fibers are considered as high performance engineering materials due to their following properties:

- Superior micro structural properties, small grain sizes.
- As the length/diameter ratio increases, the load delivered to the fibers by the matrix material rises
- Having high modulus of elasticity. Ability of the structure to possess different properties by adding various reinforcement materials to the silica sand during glass fiber production.

The use of discontinuous (intermittent) fibers as well as the use of continuous fibers is quite common in industrial applications. The fiber length, fiber thickness, and mixing ratios of discontinuous fibers are the important parameters affecting the material properties [2].

1.3. Joining of Plastics and Hot Plate Welding

Materials selection, process, and joining methods in industrial applications are constantly questioned by designers. Complex products are converted to their final forms after producing various pieces and using different joining methods. The joining of plastics are carried out using one three main methods, namely, mechanical assembly, welding, and bonding [3,4]. In welding of thermoplastics, the joint surfaces of similar and dissimilar materials are melted. Welding is carried out as the result of time dependent crystallization occurring at the joint surfaces by maintaining the pieces under pressure for a certain amount of time. The welding process is basically divided into two methods as exterior and interior. Hot plate welding (HPW), one of the external heating methods, is among the widely used welding methods applied in thermoplastics since the 1960s [5-9].

1.4. HPW Parameters

In hot plate welding, the joint surfaces of plastic pieces are heated by heat conduction or radiation by a hot plate. Welding is carried out by pressing the plastic pieces mutually that have reached their melting temperatures. Basically, all thermoplastics and elastomers whose melting temperature ranges are below the degradation temperature can be combined among each other by welding. However, some amorphous and partially crystalline thermoplastics require specially equipped hot plate welding machines to be joined with each other. These devices enable a sound welding if the same level of viscosity temperatures is obtained for different thermoplastics [10-12]. The parameters that affect the joint strength in hot plate welding method are; material (material type, mer structure, molecular weight, reinforcement materials etc.), hot plate temperature, heating time, joining pressure, weld displacement, and welding time.

1.5. Taguchi Experimental Design Method

Taguchi method is an experimental design method that minimizes the variability in product and process by selecting the optimum combination of controllable levels of factors against uncontrollable factors causing variability [13]. This method is effective for the improvement of product quality as well as obtaining better results with fewer trials in quality enhancement [13-15]. Moreover, philosophically it predicts the assurance of quality in design and process stages [16]. In this method, one of observation method, sorting method, column differences method, variance analysis (ANOVA) method and graphical representation of factor effects method is used for the determination of factor levels [17].

In this study, instead of using the conventional experimental methods for the parameter optimization of HPW process for four different parameters, Taguchi experimental design method is employed, which enables saving in the number of experiments and time. Minitab v.16 statistical analysis software is utilized in the analyses of problem data and the construction of the related graphics [18].

2. Materials and Method

2.1. PA6 GF15 Polymer Composite

In order to calculate the joint efficiency of HPW, tensile specimens from PA6 GF15 material were produced under the same conditions as the samples that were to be welded, according to TS 1149-EN ISO 294 "Plastics – Preparation of test specimens from thermoplastic materials by injection molding" standard as seen in Fig. 1.

Tensile tests have been conducted according to standard TS EN ISO 527 "Plastics- Determination of tensile properties - Part 1: General principals", in 23±1°C laboratory condition with a speed of 5 mm/min at a Shimadzu 100 kN universal testing machine. The cross sections of the tensile specimens were A_o= 32 mm^2. Percent elongations of the specimens were measured at a distance of L_o= 50 mm. The average of the ultimate tensile strength of five tests has been determined as 75 MPa. The technical properties of the composite material are given in Table 1.

Table 1
Technical properties of PA6 GF15 [19]

Producer	Product Code	Density (g/cm^3)	UTS (MPa)	Elongation (%)
EPSAN	EPLAMID 6 GF 15	1.17	75	5

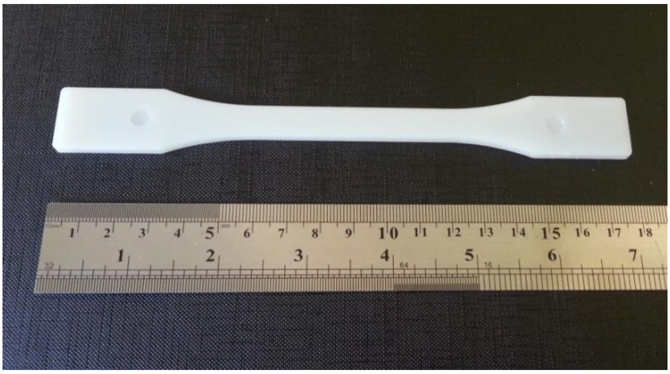

Fig. 1 Tensile test specimen

2.2. Specimen Production (Plastic Injection)

Since polyamides are hygroscopic (moisture sensitive) materials, they have to be dried in specially equipped dehumidification units before the production process depending on the amount of moisture in the material. Using the injection mold manufactured for the preparation of the specimens to be joined by the HPW method, 4x25x100 mm^3 sized specimens were molded (Fig. 2).

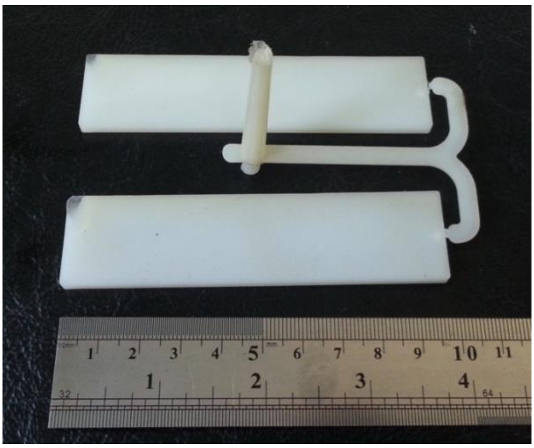

Fig. 2 Welding specimens produced by plastic injection molding

Prior to production by injection, the granular PA6 GF15 composite material was dried in the drying unit located at the top of the injection molding machine for a period of 4 hrs at 80°C. Specimens were produced in accordance with the standard TS 1149-EN ISO 294 using the injection molding machine Dr Boy 50T (Fig. 3) with 38 mm screw diameter. The production parameters of the specimens are given in Table 2.

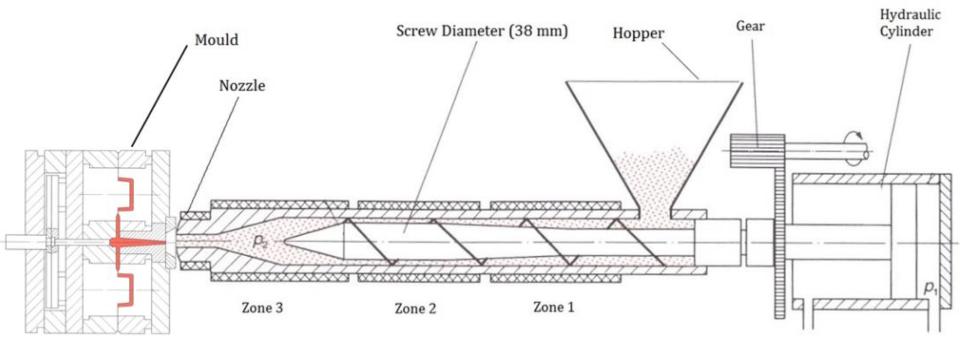

Fig. 3 Plastic injection molding machine

Table 2
Plastic injection specimen production parameters [20,21]

Material Type	Temperature (°C)				Pressure (bar)	
	Zone 1	Zone 2	Zone 3	Nozzle	P_1	P_2
PA6 GF15	220	230	240	250	50	450

2.3. Hot Plate Welding Machine

In general, welding is conducted using two principles in HPW process. The first process is carried out by controlling the pressure. In the second one, the process is carried out under motion and position control by keeping the pressure constant. The welding machine used in this study is designed according to the motion and position control principle. The HPW machine basically consists of three main units. These are the heating plate assembly, pneumatic motion assembly and the control unit. The heating plate assembly is designed to allow the surfaces to be heated independently so that thermoplastic materials can also be hot plate welded. Two of the three pistons in the pneumatic motion assembly are used for moving the specimens close to hot plates, moving them outwards after being heated and moving the specimens toward each other for welding. The third piston in the pneumatic motion assembly enables the hot plate assembly to be moved vertically. In the control unit, motions of the pistons, positioners, heaters, temperatures, plate heating times, welding times, and waiting times are controlled automatically. Fig. 4 shows the hot plate welding machine and its operation schematically.

2.4. HPW Process

The HPW process can be explained by the following steps:

- Teflon-coated surfaces of heating plates are maintained at a set temperature,
- Specimens to be welded are placed to fixtures running axially,
- Contact of the weld specimens with the heating surface is positioned by 0.01 mm accuracy using position adjustment screws,
- Welding is initiated by contacting the specimens with the hot plate and weld surfaces are heated by heat conduction,

- When the preset heating time is reached, specimens are separated from the hot plate by pulling out the horizontally moving pistons. At the same time, the hot plate changes position,
- The heated surfaces of the specimens are contacted with each other until the preset welding time and weld displacement values are reached. Afterwards, the welded specimen is removed from the machine by retracting the horizontally moving pistons (Fig. 5). The steps of the welding process are shown schematically on the pressure-time diagram (Fig. 6) [7,10,11].

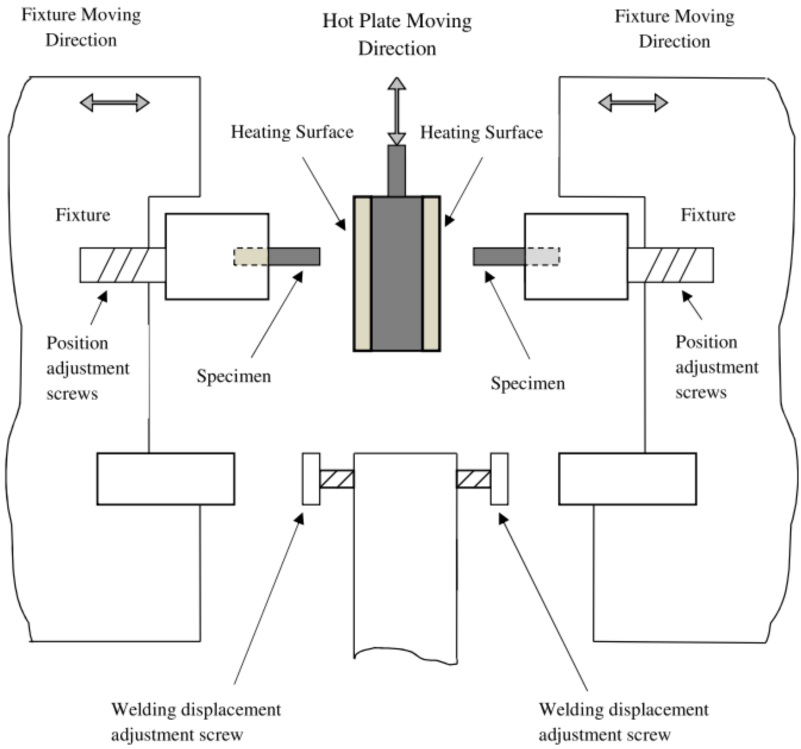

Fig. 4 Schematic diagram of HPW machine

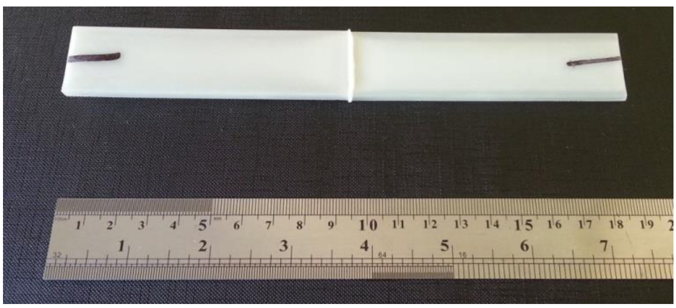

Fig. 5 Welding specimen joined by HPW

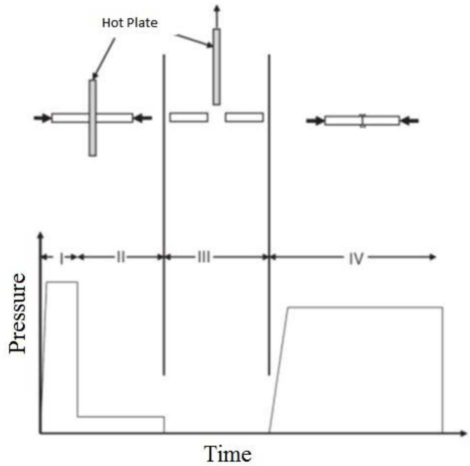

Fig. 6 Schematic pressure-time diagram showing four steps of HPW process [11]

2.5. Experimental Design for HPW Process

In this study, four welding parameters and the three levels for each were selected in accordance with the data obtained from the preliminary experimental results [7,8]. The welding parameters and levels are given in Table 3. In order to determine the effects of process parameters, experiments were performed according to experimental design principles. In the hot plate welding process for specimens, L9 orthogonal array (four columns and nine rows) was used in accordance with Taguchi experimental design method [17,22,23]. The experimental design matrix formed by L9 orthogonal array is given in Table 4. Since L9 orthogonal array is four columns, each welding parameter is assigned to one column (Table 5).

3. Results and Discussion

3.1. Analysis of Signal to Noise (S/N) Ratio

Four specimens were tested for each experimental condition to ensure the reliability of the results of tensile tests of weld specimens. Tensile tests have been conducted according to standard TS EN ISO 527 in 23±1°C laboratory condition with a speed of 5 mm/min at a Shimadzu 100 kN universal testing machine. The cross sections of the tensile specimens were measured as 32 mm^2. The results obtained by the experiments designed for PA6 GF15 and the weld strength values are shown in Table 6. For Taguchi method, signal/noise (S/N) ratio was used. The last column of Table 6 was assigned for calculated (S/N) ratios for the designed experiments [24].

Table 3 HPW process parameters and levels

Symbol	Welding Parameter	Factor Symbol	Unit	Level 1	Level 2	Level 3
A	Plate Temperature	PT	°C	250	260	270
B	Welding Displacement	WD	mm	0.50	1.00	1.50
C	Heating Time	HT	s	20	25	30
D	Welding Time	WT	s	10	15	20

Table 4
L9 Orthogonal array

Experiment No	HPW Process Parameters			
	A	B	C	D
	Plate Temperature (°C)	Welding Displacement (mm)	Heating Time (s)	Welding Time (s)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 5
L9 Orthogonal array for HPW process parameters and levels

Experiment No	Welding Parameters			
	A	B	C	D
	Plate Temperature (°C)	Welding Displacement (mm)	Heating Time (s)	Welding Time (s)
1	250	0.50	20	10
2	250	1.00	25	15
3	250	1.50	30	20
4	260	0.50	25	20
5	260	1.00	30	10
6	260	1.50	20	15
7	270	0.50	30	15
8	270	1.00	20	20
9	270	1.50	25	10

In the Taguchi experimental design method, the term 'signal' represents the desirable (mean) value for the output characteristic and the term 'noise' represents the undesirable value (S.D.) for the output characteristic. S/N ratio can be defined the ratio of the average values (M) to the square of the deviations (S.D.) statistically (Eq. 1). Taguchi method was used for obtaining S/N ratio to measure quality/process characteristic deviating from the desired value. S/N ratio is calculated by Eq. 1 [25].

$$\text{S/N ratio} = -10\log(\text{MSD}) \qquad (1)$$

where *MSD* is the mean-square deviation for the output characteristic in process. In the HPW process, since maximum weld strength is desired [17], the mean-square deviation (*MSD*) for "the higher- the better" quality characteristic can be expressed as:

$$\mathrm{MSD} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \tag{2}$$

where n is the number of tests and y_i is the value of output characteristic for the i th test. Table 6 shows weld strength values for PA6 GF15 and the S/N ratios calculated by Eqs. 1-2. These values were calculated by using statistical analysis software Minitab v.16 [24].

Table 6
Experimental results for welding strength and HPW efficiency and S/N ratios

Experiment No	Welding Parameters				Mean Welding Strength (MPa)	HPW Efficiency (%)	Calculated S/N Ratios (dB)
	A	B	C	D			
	PT (°C)	WD (mm)	HT (s)	WT (s)			
1	250	0.50	20	10	22.22	0.30	26.5839
2	250	1.00	25	15	26.01	0.35	26.0076
3	250	1.50	30	20	18.82	0.25	20.7646
4	260	0.50	25	20	45.98	0.61	30.2293
5	260	1.00	30	10	45.67	0.61	32.7736
6	260	1.50	20	15	33.82	0.45	28.5085
7	270	0.50	30	15	55.23	0.74	34.8403
8	270	1.00	20	20	47.09	0.63	33.4239
9	270	1.50	25	10	44.19	0.59	32.9016

3.2. Analysis of Variance (ANOVA)

To express the effects of different welding parameters on tensile strength, variances are analyzed (ANOVA). The purpose of the analysis of variance (ANOVA) is to investigate statistically which welding parameters significantly affect the quality/process characteristics [26]. In this analysis, plate temperature, welding displacement, heating time, and welding time are process input variables, and weld strength represents output variable (Table 7).

Table 7
Results of the ANOVA for weld strength

Welding Parameter		DOF (f)	Sum of Squares (S)	Mean square (Var.)	Variance Ratio (F)	Sum of Squares (S´)	Percent Contrib. (%)
PT	A	2	1129.96	564.98	-	-	85.76
WD	B	2	134.57	67.28	-	-	10.21
HT	C	2	50.91	25.45	-	-	3.86
WT	D	2	2.09	1.04	-	-	0.16
Error	e	0					
Total		8	1317.52				100.00

The error factor for variance V_e=0 then F_A= V_A/V_e is indeterminate since the denominator is zero. Likewise, F_B, F_C, and F_D are also indeterminate (Table 7). For this reason, to find the new error variance V_e should be pooled in smallest variance [27]. When Table 7 is analyzed since factor D has the smallest variance (i.e. welding time, WT). Factor D should be pooled. The calculated values after pooling of factor D is retabulated by Minitab v.16 (Table 8) [24].

Table 8
Results of the ANOVA for weld strength after pooling

Welding Parameter		DOF (f)	Sum of Squares (S)	Mean square (Var.)	Variance Ratio (F)	Sum of Squares (S´)	Percent Contrib. (%)
PT	A	2	1129.96	564.98	541.04	1127.87	85.74
WD	B	2	134.57	67.28	64.43	132.48	10.07
HT	C	2	50.91	25.45	24.37	48.82	3.71
Error	e(D)	2		1.04	1.00		0.48
Total		8	1317.52				100.00

The variance ratios (F) in Table 8 and Fisher's test significance levels in Table 9 can be evaluated together. Fisher's test significance levels of factors affecting HPW process of PA6 GF15 polymer composite can be summarized in Table 10. Because F value (541.04) for the plate temperature in HPW process is greater than $F_{0.005}$ (2.2) which is theoretically calculated Fisher test value for this parameter, significance level is greater than 99.5% as seen from the Table 10. Similarly, F values for welding displacement and heating time are greater than $F_{0.05}$ (2.2), and then significance levels for factors B and C are greater than 95% [28].

Table 9
Fisher test – Significance levels [29]

$F_\alpha(f_1,f_2)$	Significance Level	Confidence Level (%)	Fisher Test Value
$F_{0.005}$ (2,2)	0.50	99.5	199.0
$F_{0.01}$ (2,2)	1.00	99.0	99.00
$F_{0.05}$ (2,2)	5.00	95.0	19.00

f_1:Degree of freedom for variable factor
f_2: Degree of freedom for error factor

Table 10
Significance levels of HPW parameters

Factor	Symbol	Variance Ratio (F)	F-Test Significance Level (%)
PT	A	541.04	>99.5
WD	B	64.43	>95.0
HT	C	24.37	>95.0

3.3. Main Effects Plot for Means, S/N Ratios and Result Tables

Since the experimental design is orthogonal, it is then possible to separate out the effect of each welding parameter at different levels. For example, the mean S/N ratio for the plate temperature at levels 1, 2 and 3 can be calculated by averaging the S/N ratios for the experiments 1-3, 4-6, and 7-9, respectively. The mean S/N ratio for each level of the other welding parameters can be computed in a similar manner. As a result of the analysis performed by Minitab V.16, the S/N ratio for each level of the welding parameters is summarized and called the S/N response table for weld strength (Table 11) and main effects graph for weld strength-S/N ratios is plotted (Fig. 7). Similarly, response table (Table 12) and main effects graph (Fig. 8) for mean weld strength values is summarized and plotted [24].

Table 11
Response table for weld strength-S/N Ratio

Level	Factor		
	A	B	C
	Plate Temperature (°C)	Welding Displacement (mm)	Heating Time (s)
1	24.45	30.55	29.51
2	30.50	30.74	29.71
3	33.72	27.39	29.46
Max.	33.72	30.74	29.71
Min.	24.45	27.39	29.46
Delta	9.27	3.35	0.25
Rank	**1**	**2**	**3**

Table 12
Response table for weld strength-Means

Level	Factor		
	A	B	C
	Plate Temperature (°C)	Welding Displacement (mm)	Heating Time (s)
1	22.35	41.15	34.38
2	41.83	39.59	38.73
3	48.84	32.28	39.91
Max.	48.84	41.15	39.91
Min.	22.35	32.28	34.38
Delta	26.49	8.87	5.53
Rank	**1**	**2**	**3**

3.4. Evaluation of Experimental Results

3.4.1. Contribution of factors to weld strength

The contribution of welding factors in HPW process as percentage contribution (%P) is calculated separately with the help of Minitab V.16 and they are tabulated in the last column of Table 8. The percentage of contribution is a function of the sum of squares for each significant item and it is the ratio of sum of squares (S') to the total of sum of squares (S_T) [24]. For instance, the percentage of contribution for plate temperature P_A is calculated as follows:

$$P_A = \frac{S'_A}{S_T} = \frac{1129.96}{1317.52} = 0.8574 \quad P_A = 85.74\ \%$$

The percentage contribution of HPW process parameters for PA6 GF15 is shown in Fig. 9. It can be seen that the most dominant welding parameter is plate temperature (PT) for PA6 GF15 from the ANOVA table in Table 8 and Fig. 9.

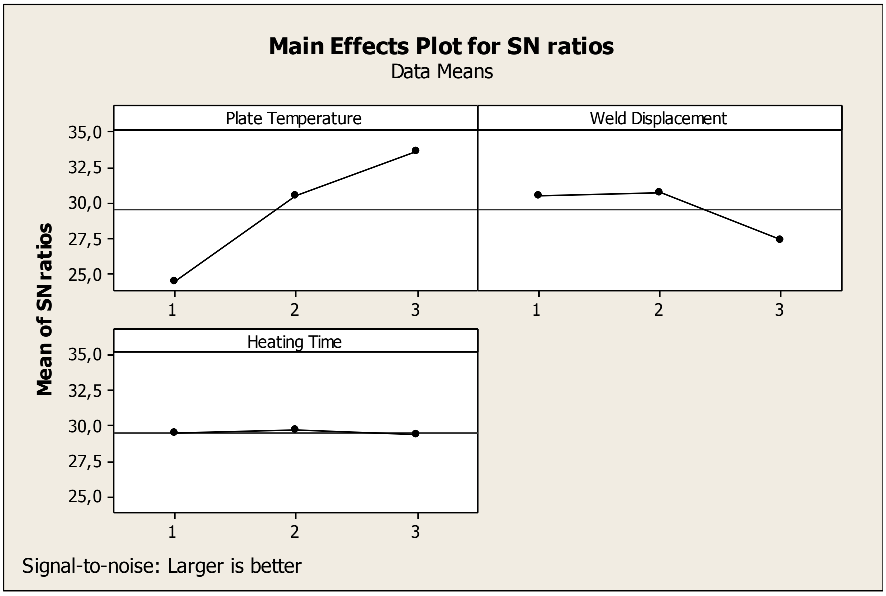

Fig. 7 Main effects plot for weld strength - S/N ratios

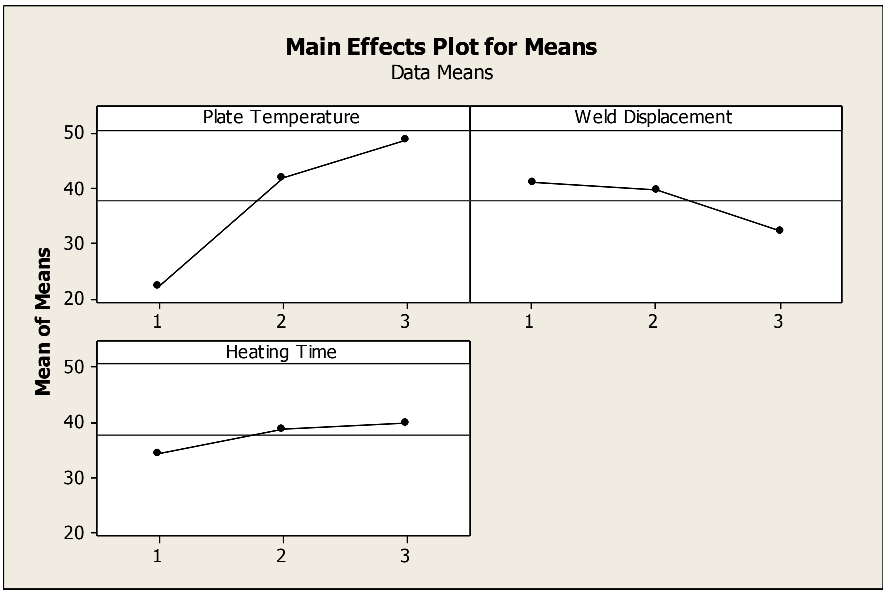

Fig. 8 Main effects plot for weld strength - Means

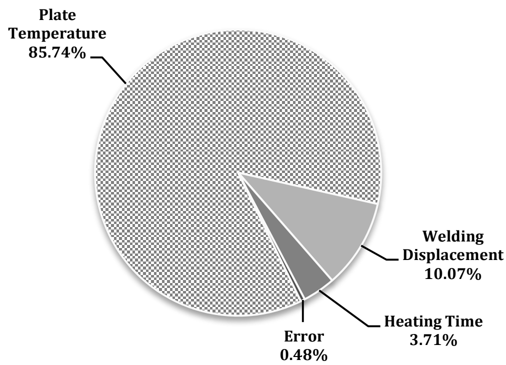

Fig. 9 Contributions of HPW parameters to weld strength

3.4.2. Prediction of optimal weld strength

Based on the results of tensile tests for PA6 GF15 weld specimens and according to S/N ratio response table (Table 11) and main effects plot (Fig. 7), optimum welding parameters are determined as A3B2C2 having the highest S/N ratio. In Table 13 optimum welding parameters and levels are given. If plate temperature (A), welding displacement (B), and heating time (C) are set to the levels 3, 2, and 2 respectively, optimal welding strength will be reached based on the Taguchi experimental design method (Table 13).

Table 13
Optimal welding parameters and levels

Optimal Welding Parameters and Levels	A	B	C
	Plate Temperature (°C)	**Welding Displacement (mm)**	**Heating Time (s)**
A3B2C2	270	1.0	25

3.4.3. Calculation of optimal weld strength and HPW efficiency

Since optimal welding parameters for weld strength are A3B2C2, optimal weld strength (WSopt) is calculated by Eq. 3 [14,17,30].

$$\mathrm{WS_{opt}} = \mathrm{A_3} + \mathrm{B_2} + \mathrm{C_2} + 2\mathrm{T_m} \quad (3)$$

where T_m is the average of mean weld strength values (37.67 MPa) in Table 6 and WS_{opt} can be calculated as below:

$$\mathrm{WS_{opt}} = 48.84 + 39.59 + 38.73 + 2(37.67) = 51.81 \text{ MPa}$$

HPW efficiency corresponding to the weld strength of 51.81 MPa is calculated according to Eq. 4.

$$\text{HPW Efficiency (\%)} = \frac{\mathrm{WS_{opt.}}}{\sigma_{\mathrm{PA6GF15}}} \quad (4)$$

where $\sigma_{PA6\ GF15}$ is given as ultimate tensile strength of PA6 GF15 polymer composite (75 MPa) in Table 1.

$$\text{HPW Efficiency (\%)} = \frac{51.81}{75} = 69\%$$

S/N ratio for optimum welding strength (WS_{opt}) is calculated by the Eq. 5 derived from Eqs. 1 and 2 [14,17].

$$\text{S/N Ratio} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \tag{5}$$

If y_i is substituted by WS_{opt} in Eq. 4, Eq. 4 can be written as Eq. 6 as below:

$$\text{S/N Ratio} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{WS_{opt}^2}\right) \tag{6}$$

S/N ratio is calc0u0lated as 34.2890 dB. The calculated WS_{opt} and S/N ratios are given in Table 15.

3.4.4. Confirmation experiments

The final step after determining the optimum welding parameters is the confirmation of the improvement in the weld strength by using optimal welding parameters. The main effects plot for weld strength for S/N ratios which is used for optimal welding parameters, is also utilized to determine the initial welding parameters. The initial welding parameter levels are found as A2B1C1, which represent the levels closest to the average levels in Fig. 7 and corresponding levels are also shown in Table 14.

Table 14
Initial welding parameters and levels

Initial Welding Parameters and Levels	A	B	C
	Plate Temperature (°C)	**Welding Displacement (mm)**	**Heating Time (s)**
A2B1C1	260	0.5	20

3.4.5. Calculation of initial weld strength and HPW efficiency

Since initial welding parameters for weld strength are A2B1C1, initial weld strength (WS_i) is calculated by Eq. 7 resembling Eq. 4 [14,17].

$$WS_i = A_2 + B_1 + C_1 + 2T_m = 41.83 + 41.15 + 34.38 + 2(37.67) = 42.01\ \text{MPa} \tag{7}$$

HPW efficiency corresponding to weld strength of 42.01 MPa is calculated according to the Eq. 8.

$$\text{HPW Efficiency (\%)} = \frac{WS_i}{\sigma_{PA6GF15}} \tag{8}$$

$$\text{HPW Efficiency} = \frac{42.01}{75} = 56\%$$

S/N ratio for initial welding strength WS_i is calculated by the Eq. 5 and found as 32.4662 dB. The calculated WS_i and S/N ratios are given in Table 15.

After setting the optimal welding parameters to maintain the reliability of confirmation experiments, HPW process is repeated with four specimens and average tensile test results of four weld specimen are shown in Table 15. The confirmation experiments show that the weld strength gain is about 27%. The S/N ratio is improved by 2.0684 dB and the weld strength is increased 11.29 MPa from the initial welding parameters to the optimal welding parameters (Table 15).

Table 15
Results of confirmation experiment

	Initial Welding	**Optimal Welding**		**Improvement**
	Exp.	**Prediction**	**Exp.**	
Parameter Levels	A2B1C1	A3B2C2	A3B2C2	%27
Welding Strength (MPa)	42.01	51.81	53.30	-
Calculated S/N Ratio (dB)	32.4662	34.2890	34.5345	2.0684
HPW Efficiency (%)	56	69	71	-

3.5. Discussion

In this study, Taguchi experimental design method was used to investigate the optimal welding parameters of HPW process of PA6 GF15 composite material. Through the use of this method, the number of experiments and time required to investigate the effectiveness of the welding parameters are reduced and experimental efficiency has been achieved in the studies. As a result of experimentation using L9 orthogonal array, improvements in weld strength were obtained and Taguchi method has been successfully applied. Experimental and analytical results for HPW of PA6 GF15 composite materials are as follows:

- Plate temperature is the most dominant factor for HPW process,
- The optimum welding parameters for the hot plate weld strength are plate temperature of 270°C, welding displacement of 1 mm, heating time of 25s,
- The confirmation experiments show that the weld strength gain is about 27% from the initial welding parameters to the optimal welding parameters,
- HPW efficiency has increased from 56% to 71%.

Based on this study, in order to confirm the experimental results obtained for PA6 GF15 polymer composite materials, numerical modeling and simulations can be applied. Also the experimental and modeling studies are recommended for HPW applications on PA6 and its glass fiber reinforced types.

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References

1. Yeni Ç, Sayer S, and Ülker A. Conditioning polyamide parts by dehumidification after production, PAGEV–Plastik, 2010; 111: 296 – 302.
2. Strong AB. Plastics materials and processing, 3rd edition, New York, Prentice Hall, 1999: 1-16, ISBN-13: 978-0131145580.
3. Sayer S. Hot plate welding applications in thermoplastics, PAGEV–Plastik, 2009; 104: 128 – 132.
4. Sayer S, Yeni Ç, and Ülker A. Principles of joining of thermoplastics by welding and technological innovations – Part 1, PAGEV–Plastik, 2012; 122: 118 – 124.
5. Grewell D, Benatar A, and Park JB. Plastics and Composites Welding Handbook, München, Hanser Verlag, 2003: 11-68, ISBN-13: 978-1569903131.
6. Grewell D and Benatar A. Welding of plastics: fundamentals and new developments. International Polymer Processing, 2007; 22: 43 – 60.
7. Ehrenstein GW. Handbuch kunststoff verbindungstechnik, München, Hanser Verlag, 2004: 179-206, ISBN-13: 978-3446226685.
8. Troughton M. Handbook of plastics joining – A practical guide, 2nd edition, New York, William Andrew Inc., 2008: 3-13, ISBN-13: 978-0815515814.
9. Stokes VK. Joining methods for plastics and plastic composites: An overview. Polymer Engineering and Science, 1989; 20: 1310 – 1318.
10. Stokes VK and Conway KR. A phenomenological study of the hot-tool welding of thermoplastics 4, Weld strength data for several blends – Test, 2004; 42: 7477 – 7493.
11. Stokes VK. A phenomenological study of the hot-tool welding of thermoplastics, Polymer, 1999; 40: 6235 – 6263.
12. Lee B, Kim J, Lee S, and Kim YK. Butt–welding technology for double walled polyethylene pipe. Materials and Design, 2012; 35: 626 – 632.
13. Canıyılmaz E. Taguchi method and an application in quality development, M.Sc. Thesis, Gazi University, Ankara, Turkey, 20-35, 2001.
14. Ross PJ. Taguchi techniques for quality engineering, Singapore, McGraw-Hill, 1996: 23-61, ISBN-13: 978-0070539587.
15. Şirvancı M. Design of experiments approach for quality – Taguchi approach, İstanbul, Literatür, 1997: 75-100,ISBN 979-975-786-087-6.
16. Genichi T and Clausing D. Robust quality. Harvard Business Review, 1990; January: 65 – 76.
17. Roy RK. A Primer on the Taguchi method, New York, Van Nostrand Reinhold, 1990: 41-154, ISBN-13: 978-0442237295.
18. MINITAB. User's guide 2: Data Statistical and quality tools- Release 13 for windows, 2000: 24-1 - 24-35, ISBN 0-925636-44-4.
19. http://www.epsan.com.tr
20. http://www.enformak.com
21. Meric A., Akcan A, Arcan G, and Cayit F. Plastics, injection and extruders, İstanbul, Enformak, 2011: 85 – 88.
22. Phadke MS. Quality engineering using robust design, New York, Prentice-Hall, 1989: 41-128, ISBN-13: 978-0137451678.

23. Yang WH and Tarng YS. Design optimization of cutting parameters for turning operations based on the Taguchi method. Journal of Materials Processing Technology, 1998; 84: 122 – 129.
24. http://www.minitab.com
25. Peace GS. Taguchi methods: A hands-on approach, New York, Addison– Wesley, 1993: 50-83, ISBN-13: 978-0137451678.
26. Campanelli LC. Parameters Optimization for Friction Spot Welding of AZ31 Magnesium Alloy by Taguchi Method. Soldagem Insp. Sao Paolo, 2012; 17(1): 026 – 031.
27. Saatcioglu O. Quality engineering - Unpublished lecture notes, Middle East Technical University, Ankara, Turkey, 1993.
28. Montgomery DC. Design and analysis of experiments, 5th edition, New York, John Wiley and Sons, 2001: 37-43, ISBN-13: 978-1118146927.
29. Fisher RA. The design of experiments, Edinburgh, Oliver and Boyd, 1935:13-25, ISBN-13: 978-0028446905.
30. Lakshminarayanan AK and Balasubramanian V. Process parameters optimization for friction stir welding of RDE-40 aluminium alloy using Taguchi technique. Transactions of Nonferrous Metals Society of China, 2008; 18: 548 – 554.