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An Experimental Investigation of Ultrasonic welding on Thermoplastic material

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Abstract —*Rapid performance and the absence of filler material in Ultrasonic welding has established itself as one the most effective techniques in manufacturing industry for fusing plastic assemblies. Faster joining and reliable process for developing plastic utility has increased in past decade. In Ultrasonic welding, by applying high-frequency vibratory energy and pressure, thermoplastics materials are joined. Because of high-quality joints and low cost of Ultrasonic welding of Thermoplastic materials has become a popular process in the industry. In this research, experimental data of welding strength of acrylonitrile butadiene styrene (ABS) and Polycarbonate (PC) of material for ultrasonic welding are studied. For the investigating the significant effect of process parameters of ultrasonic welding, various welding parameters like Amplitude, Weld time and Welding Pressure has been studied. In order to determine critical states of the welding parameters, Full Factorial methods is employed as Design of Experiments and analysis of variances has applied while optimization of the parameters affecting the welding strength has been achieved with the Response Surface Methodology.*

Keywords- *Ultrasonic Welding, Thermoplastic Material, Process Parameters, Tensile Strength, Full Factorial Method, ANOVA, Response Surface.*

I. INTRODUCTION

ABS (acrylonitrile butadiene styrene) a copolymer, is made up of polymerized styrene and acrylonitrile with polybutadiene, The styrene gives the plastic a shiny and glossy impervious surface. The polybutadiene is a rubbery substance which provides toughness at even low temperatures. The nitrile makes ABS stronger than pure polystyrene. ABS has very good property of High impact resistance at low temperature, High chemical resistance to Acid and alkalis, very good toughness, shiny and glossy surface and electrical insulating properties [3]. Due to strong, tough and optically transparent characteristics Polycarbonate (PC) is widely used in engineering application. Polycarbonate material is very pliable. It can be formed at room temperature without cracking or breaking. Polycarbonate material can form small bends without application of heat. Polycarbonate has very good property of high durability, high chemical resistance to acid and alkalis, shatters resistance, lightweight, transparency, and easily machined [3].

Joining of ABS to PC has already found numerous application in automotive industry, Consumer goods, Enclosures for electrical and electronics, kitchen appliances and medical industry.

In an Ultrasonic Welding, Solid state of weld is created by holding the work-pieces together under pressure and by applying ultrasonic vibration to work-pieces [1]. It is commonly used for plastics and metals, and especially for joining dissimilar materials. In ultrasonic welding, does not require soldering materials, or adhesives, connecting bolts, and hard nails, necessary to join the materials together.

In the present research, an experimental investigation of Ultrasonic welding of dissimilar plastics between ABS & PC has been carried out. Response surface methodology (RSM) is employed to develop mathematical relationships between the welding process parameters namely Amplitude, Pressure and Weld time and the output variable Welding Strength. The developed mathematical model is tested by analysis-of-variance (ANOVA) method to check its competence. This mathematical model is useful for predicting the weld strength as well as for selecting the optimum process parameters. The influence of process parameters on weld strength are discussed based on the main effect and interaction plots.

II. EXPERIMENT

2.1. Experimental Setup

The experiment was carried out on pneumatic ultrasonic press USP2500. Table 1 shows the specification of Ultrasonic welding machine. The actual experimental setup is shown in figure 1. For the given Ultrasonic welding machine, welding

horn was made of EN 24 (AISI 4340) material. The ideal amplitude for the Ultrasonic welding machine is 20µm peak/peak at 100% selection.

Table 1. Machine Specification

Description	Value
Power Supply	220V 50Hz +20% -10%
Working Frequency	20KHz
Idle Amplitude	20µm peak/peak at 100% selection
Max. Power	2000W effective
Max. Converter Voltage	1700V effective

Figure 1. Experimental Setup

2.2. Welding Parameters

An experiment is designed such that, the information about the parameters affecting the process and inference of the parameter in the system can be drawn with minimum of efforts & time. The first & foremost consideration is to select the independent or confounding parameters which are to be controlled & the response parameters that are to be measured for the quality of performance of the process. The key parameters for ultrasonic welding are Amplitude, Frequency, Weld time and Pressure. It was observed that Amplitude, pressure and weld time are affecting parameters for this process. The value of amplitude is taken in percentage as the ideal amplitude of machine is 20µm peak/peak at 100% selection. Below Table 2 shows the selected values of Welding parameters.

Table 2. Welding Factors & Levels

	Designation	Level 1	Level 2	Level 3
Amplitude (%)	A	70	80	90
Pressure (bar)	B	3	3.5	4
Weld time (Sec)	C	1.5	1.6	1.7

2.3. Methodology

In this Experimental research the test specimens were prepared according to standard EN 12814-3. The specimen selected for experiment are, ABS of 70 mm x 10 mm x 2mm thickness and PC of 70 mm x 10 mm x 2 mm thickness. Full factorial method was employed as design of experiments with 3 input factors and 3 Levels. Total 54 runs were performed with 2 replicates. During the Study, as a response parameter welding strength of ABS of PC was measured using universal tensile testing machine. Analysis of Variance (ANOVA) was used to identify the significant effect of the influencing parameters on the Welding strength of Ultrasonic welded specimen. Also, the SEM images of cross section at center of ultrasonic weld of samples were studied to check the evolution of bond between ABS & PC.

III. RESULTS & DISCUSSION

Total 54 runs were performed using Full factorial design response surface method with two replicates to measure welding strength of ABS & PC joint. Statistical software MINITAB 14 was used to code the design matrix and analyze the main effect and interaction effect of the process parameters.

Table 3. Design Matrix with Experiment Result

Sr. No.	Weld Amplitude (%)	Weld Pressure (bar)	Weld Time (sec)	Weld Strength (Mpa)	Sr. No.	Weld Amplitude (%)	Weld Pressure (bar)	Weld Time (sec)	Weld Strength (Mpa)
1	70	3	1.5	15.6887	28	70	3	1.5	14.7712
2	70	3	1.6	15.7848	29	70	3	1.6	12.9026
3	70	3	1.7	15.8808	30	70	3	1.7	10.1165
4	70	3.5	1.5	13.306	31	70	3.5	1.5	12.5121
5	70	3.5	1.6	13.4	32	70	3.5	1.6	7.6378
6	70	3.5	1.7	13.498	33	70	3.5	1.7	12.0253
7	70	4	1.5	12.4895	34	70	4	1.5	11.493
8	70	4	1.6	12.5855	35	70	4	1.6	12.197
9	70	4	1.7	12.6816	36	70	4	1.7	12.898
10	80	3	1.5	29.849	37	80	3	1.5	31.001
11	80	3	1.6	29.946	38	80	3	1.6	29.183
12	80	3	1.7	30.042	39	80	3	1.7	28.4757
13	80	3.5	1.5	27.467	40	80	3.5	1.5	27.1848
14	80	3.5	1.6	27.563	41	80	3.5	1.6	27.4163
15	80	3.5	1.7	27.659	42	80	3.5	1.7	27.2042
16	80	4	1.5	26.65	43	80	4	1.5	26.579
17	80	4	1.6	26.7467	44	80	4	1.6	25.224
18	80	4	1.7	26.843	45	80	4	1.7	26.898
19	90	3	1.5	16.985	46	90	3	1.5	15.4071
20	90	3	1.6	17.081	47	90	3	1.6	16.5496

21	90	3	1.7	17.1778	48	90	3	1.7	14.771
22	90	3.5	1.5	14.603	49	90	3.5	1.5	13.8535
23	90	3.5	1.6	14.701	50	90	3.5	1.6	14.2153
24	90	3.5	1.7	14.795	51	90	3.5	1.7	15.708
25	90	4	1.5	13.786	52	90	4	1.5	13.929
26	90	4	1.6	13.883	53	90	4	1.6	14.417
27	90	4	1.7	13.979	54	90	4	1.7	13.325

3.1. Analysis of Variance (ANOVA)

Table 4. Analysis of Variance

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
A	2	2379.723	2379.723	1189.862	659.03	0.000
B	2	63.908	63.908	31.954	17.70	0.000
C	2	1.051	1.051	0.525	0.29	0.750
A*B	4	4.436	4.436	1.109	0.61	0.656
A*C	4	2.746	2.746	0.686	0.38	0.821
B*C	4	6.891	6.891	1.723	0.95	0.448
A*B*C	8	6.659	6.659	0.832	0.46	0.872
Error	27	48.748	48.748	1.805		
Total	53	2514.161				
S = 1.34368		R-Sq = 98.06%		R-Sq(adj) = 96.19%		

From the ANOVA results it was observed that Amplitude and Pressure are the most significant factors affecting the ultrasonic welding of ABS and PC of 2 mm thickness strip. The p – value for both Amplitude and Pressure was less than 0.05. Thus, it can be concluded that Amplitude and Pressure are the statistically significant parameter. For the Investigation of experiment, confidence level (CL) was considered 95%. The Parameter R-Sq describes the amount of variation observed in weld strength is explained by input factors. R-Sq = 98.06%, which indicates that model is able to predict the response with high accuracy.

The final equation for the joint strength can be given by the following equation:

$Y = -708.034 + 22.2737*A - 34.1838*B - 118.594*C - 0.13968*A^2 + 3.19094*B^2 + 24.0711*C^2 - 0.0321*A*B + 0.18135*A*C + 7.44692*B*C$

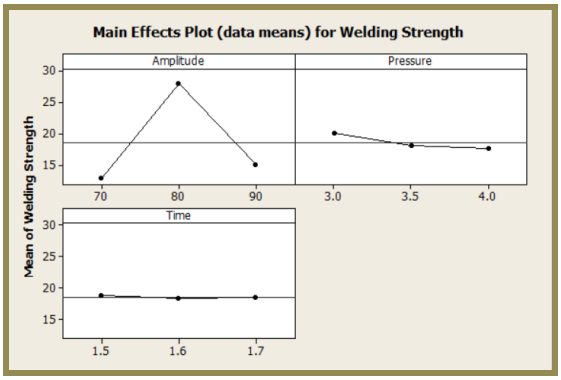

Figure 2. Main Effects Plot

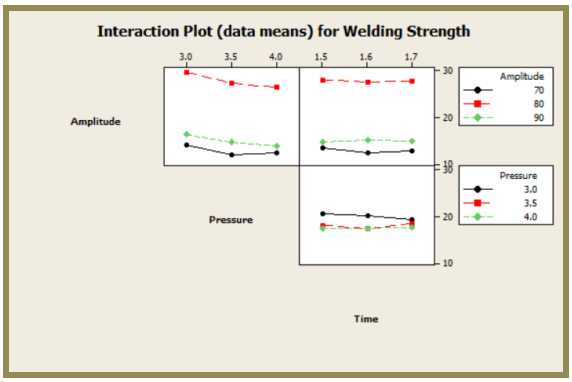

Figure 3. Interaction Plot

Figure 2 shows the main effects plot for Amplitude, Pressure and time. It was observed that with increase in amplitude, Weld strength increases and then after 80% of amplitude Weld strength decreases. The highest strength is obtained at Amplitude of 80% of 27.8851 MPa. With increase in Amplitude will increase the weld quality.

It was observed that with increase in Pressure, weld strength decreases. The Weld strength of 20.0896 MPa was observed at 3 bar pressure and then it reduced to 18.0416 Mpa at 3.5 bar and further reduced to 17.5891 Mpa at 4.0 bar pressure.

The nature of decrease in weld strength was observed linear with Weld time and Pressure. At time of 1.5 sec weld strength was 18.7531 MPa was observed and then it reduced to 18.4130 Mpa at 1.6 sec and slightly increased to 18.5543 Mpa at 1.7 sec.

Figure 3 shows the interaction effect plot at Data means of weld strength. It shows that Lower pressure and medium amplitude gives the higher weld strength of 29.7495 MPa. Also a combination of lower time and medium amplitude gives the good strength. But a combination of medium pressure and lower amplitude shows the decrease in weld strength.

Fig. 4 & 5 shows the contour plot and surface plot of Welding Strength for interaction of Amplitude and pressure, when welding time is taken as hold. The contour and surface plots clearly depicts that welding strength is less at higher pressure and higher amplitude. Higher welding strength was observed at medium amplitude and lower pressure. It was also observed that keeping amplitude at medium level and increasing pressure gives good welding strength.

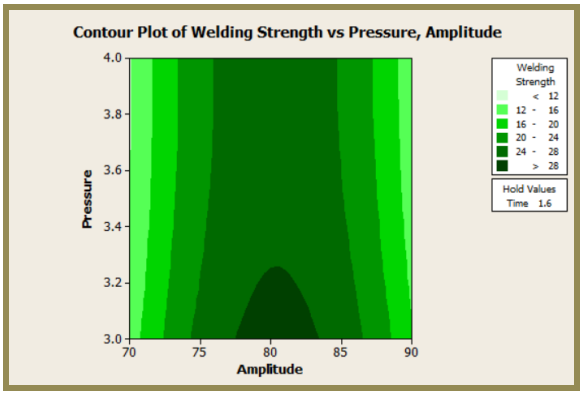

Figure 4. Contour plot of Welding strength Vs Amplitude, Pressure

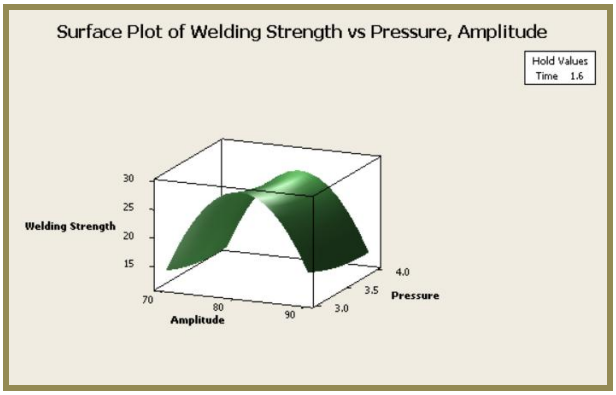

Figure 5. Surface plot of Welding strength Vs Amplitude, Pressure

Figure 4 & 5 shows the contour plot and surface plot of Welding Strength for interaction of Amplitude and pressure, when welding time is taken as hold. The contour and surface plots clearly depicts that welding strength is less at higher pressure and higher amplitude. Higher welding strength was observed at medium amplitude and lower pressure. It was also observed that keeping amplitude at medium level and increasing pressure gives good welding strength.

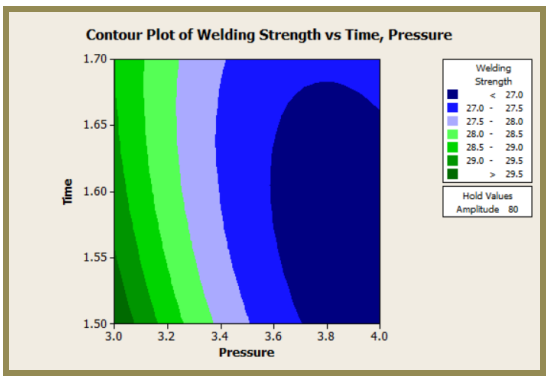

Figure 6. Contour plot of Welding strength Vs Time, Pressure

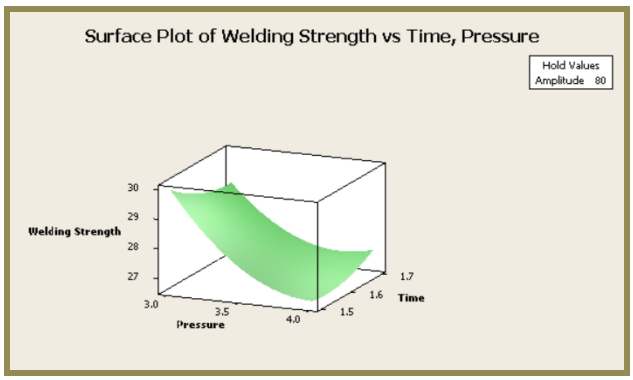

Figure 7. Surface plot of Welding strength Vs Time, Pressure

Figure 6 & 7 shows the contour plot and surface plot of Welding Strength for interaction of Pressure and Time, when Amplitude is taken as hold. Higher welding strength at lower welding time and lower pressure was observed. Also increase in welding time and increase in pressure, weld strength has decreased.

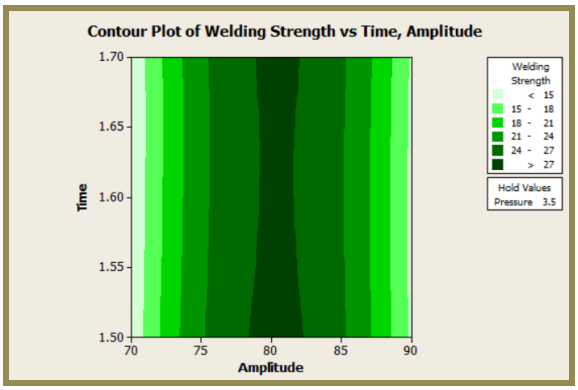

Figure 8. Contour plot of Welding strength Vs Time, Amplitude

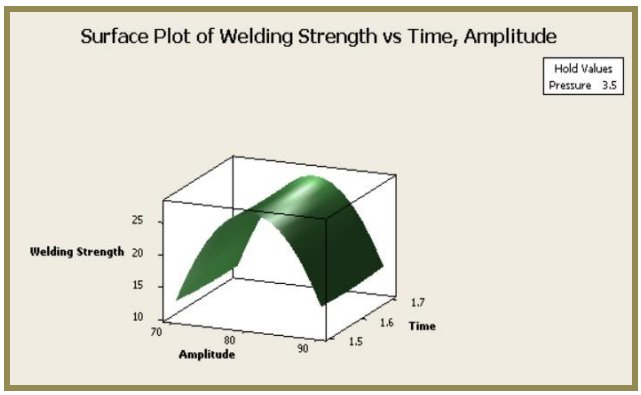

Figure 9. Surface plot of Welding strength Vs Time, Amplitude

Figure 8 & 9 shows the contour plot and surface plot of Welding Strength for interaction of Amplitude and time, when pressure is taken as hold. The contour and surface plots clearly depicts that welding strength is less at higher welding time and higher amplitude. Higher welding strength was observed at medium amplitude and lower time. It was also observed that keeping amplitude at medium level and increasing time gives good welding strength and remains almost same.

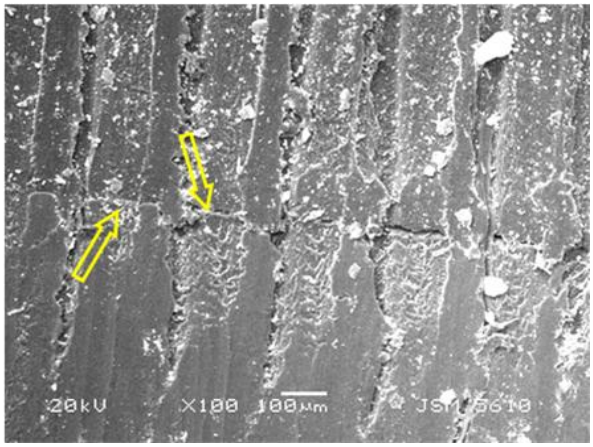

Figure 10. Cross sectional SEM micrograph at center of USW at x100

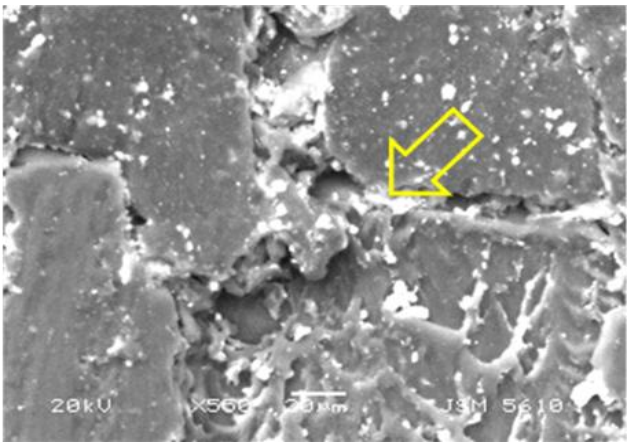

Figure 11. Cross sectional SEM micrograph at center of USW at x550

Fig. 10 and 11 shows the SEM micrograph of cross section at ultrasonic weld with 80% of amplitude, 3 bar of pressure and 1.5 sec of weld time. Fig.10 is taken at x100 and 100µm. Fig. 11 is the magnified view at x550 and 20 µm. It clearly shows that at 80% amplitude ABS and PC are melted and at Pressure of 3 bar, ABS and PC are penetrated to each other and thus creating the good quality of weld. SEM images validates results observed in interaction plot which is at medium amplitude and low pressure good quality of weld and higher weld strength can be achieved.

IV. CONCLUSION

In the present paper, experimental investigation of ultrasonic welding process parameter optimization has been performed on ABS & PC as non-metallic material. The following conclusions can be drawn from the experimental investigation carried out within given condition of experiement.

- ANOVA analysis results shows that amplitude and pressure are statistically significant parameters for the ultrasonic welding process of ABS and PC of 2mm thick strips as the p-value of amplitude and pressure is less than 0.05.

- While studying the main effect of the welding parameters, it was observed that Amplitude and Pressure are the significant factors for welding strength. It was observed that with increase in amplitude weld strength increases and after 80% of amplitude weld strength decreases. This is due to fact that after 80% of amplitude as the amplitude increases it creates more frictional heat between the mating surfaces of work-piece. Also due to higher frictional heat par melts which leads to weak welding strength. Highest welding strength of 27.8851 MPa was observed at 80% of amplitude and then it decreased to 14.9537 MPa at 90% of amplitude.

- It was observed that pressure is also a significant parameter of the experiment. A linear relationship of pressure and welding strength was observed. With increase in pressure, welding strength decreases. This is due to fact that with increase in pressure, sonotrode of the welding horn creates impression on the work-piece which leads to improper welding bond at the mating surfaces of the work-piece. Good welding strength of 20.0896 MPa was observed at low pressure of 3 bar and then it decreased to the 17.5891 MPa at high pressure of 4 bar.

- It was observed that Welding time is not a influencing parameter in the ultrasonic welding process of the experiment. Welding strength was observed almost same with increase in weld time.

- It was observed through SEM micrograph that 80% amplitude, 3 bar pressure and 1.5 Sec of Weld time gives good quality of weld where as lower values of amplitude 70%, 3.5 bar pressure and 1.5 sec weld time gives poor weld quality.

- Highest welding strength of 29.7495 MPa was observed with 80% of amplitude and low pressure of 3 bar.

- Thus, it can be concluded that Pressure and Amplitude are the most significant parameters for the given condition of experiment.

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