EXPERIMENTAL STUDY ON TEMPERATURE DISTRIBUTION, HEAT GENERATION AND BONDING STRENGTH OF ULTRASONIC WELDING ON ABS & HDPE MATERIALS

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ABSTRACT: Ultrasonic plastic welding has received significant attention in the past few years, and has become more reliable and suitable for a wide range of applications. In recent years, technique has been extensively used due to the advent of component miniaturization and improvements in producing lightweight components. There are a number of advantages for ultrasonic plastic welding, including greater efficiency and speed, longer tool life, higher accuracy and no filler or flux needed to be used. Thus the technique can be viewed as being environmentally friendly
In this work effect of various parameters on weld strength have been studied. Welding of 0.5 mm thickness Acryl nitride Butadiene-Styrene (ABS) and High Density Polyethylene (HDPE).plates were successfully welded by 20 kHz ultrasonic welding system. This experiment was carried to find out the optimum parameter for maximum strength. In order to determine critical states of the welding parameters, analysis of variances has applied while optimization of the parameters affecting the joint strength has achieved with centre composite method of the Response Surface Methodology. This study involves modeling of experimental data of joint strength of ABS & HDPE material for ultrasonic welding on welding parameters (welding pressure, welding time, and amplitude. Results are compared with Analytical values.
Keywords: Ultrasonic Welding, Thermoplastic Material, Process Parameters, Joint Strength, ANOVA, Response Surface.

I. INTRODUCTION

Ultrasonic plastic welding is the joining of plastic through the use of heat generated from high-frequency mechanical motion. It is accomplished by converting high-frequency electrical energy into high-frequency mechanical motion. That mechanical motion, along with applied force, creates frictional heat at the plastic components mating surfaces (joint area) so the plastic material will melt and form a molecular bond between the parts. No solvents, adhesives, mechanical fasteners, or other consumables are required, and finished assemblies are strong and clean. Ultrasonic plastic Welding is the fastest and most cost effective method used today to join and assembles plastic parts. Ultrasonic plastic welding is cost effective and a green technology. Ultrasonic welding eliminates the need to use fasteners, glues and/or solvents.Ultrasonic plastic Welding can be used to join all rigid thermoplastics. Ultrasonic welding uses an acoustic tool called an ultrasonic horn made to match your parts design. Ultrasonic Welding is converted to heat through friction that melts the plastic. The main components of an ultrasonic welding system are the actuator and power supply, converter/booster and ultrasonic horn, part holding weld fixture/jig. Many researchers are discussed about the ultrasonic welding process on different materials on ultrasonic plastic welding and ultrasonic metal welding Dipal M. Patel, B. Avadhoot U. Rajurkar described procedure of sonotrode design for conventional shape profile by classical method and by CARD software and presented comparison of results. Vladimir N. Khmelev, Alexey N. Sliven, Alexey D. Abramov, studied results of calculations and time dependence on a welded joint from influencing parameters, such as amplitude and frequency of ultrasonic oscillations; the area of the working tool Vijay Singh pal, Pavan Agrawal's study is Analysis of Bonding Strength of Ultrasonic Welding Process. In ultrasonic welding, high frequency vibrations are combined with pressure to join two materials together quickly and securely.Bokka Ravi Kiran, K. Gowri Shankar did a review on Thermal Analysis of Dissimilar Metal Welding Process in Laser Welding. Laser welding process has successfully used for joining of dissimilar metals i.e. copper and steel. The presented model is capable of predicting and explaining unfavorable welding conditions, therefore making it possible to predetermine weld locations on larger parts or what surface preparation of the parts to be welded would lead to an improved welding result. Furthermore, shear force at the anvil measured during welding could be correlated to changing welding conditions. This is a new approach of explaining the process of USMW, because it is based on mechanical considerations. The use of a shear force measuring anvil has the potential to be implemented into welding systems and the sheer force would provide an additional means of process control. In the present research, an experimental investigation of Ultrasonic welding of dissimilar plastics between ABS & HDPE 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.

II. PROPOSED METHODOLOGY

In this research work the specimen has prepared according to ASTM standard. The specimen selected for the experiment is ABS material having (80 × 50 mm) and 0.5 mm thickness. Total 9 run have identified Values applying design of experiment with 3 input parameters and 3 levels. Here the joint strength has measured by universal testing machine as one output parameter. During the tensile testing, ductile fracture has observed at weld interface for most of the welded samples. Analysis of variance (ANOVA) has used to identify significant effect of parameters and regression analysis have to follow to optimize parameter values for maximum joint strength. The heat generation is calculated during welding.

The various parameters are taken with different levels in this process to weld the materials used in ultrasonic welding. In this work, the controllable factors taken are Voltage, Current and pressure. Since they affect strength and welding operation and these factors are controllable in the ultrasonic welding process, they are considered as a controllable factor.

2.1 EXPERIMENTAL SETUP

The welding was carried out using a conventional ultrasonic plastic welding machine (2,500 W, 20 kHz). The specification of the machine is shown in the table 1. The actual experimental setup is as shown in Fig1 with the data acquisition system. A horn made of titanium alloy was used for this study and an anvil made of steel with serrations at the top surface. The parameters that can be varied in this setup are the weld pressure, weld time, and the amplitude of vibration. These factors are selected as the variables for this study. The area of horn that comes into contact has serrations similar to the top surface of the anvil for gripping the work piece well. The specimen (0.5 mm ABS &HDPE sheet) was prepared as per standard for testing shear strengths of the joint by tensile loading.

A universal testing machine was used to determine the weld strengths. The temperature at the interface of the specimen was monitored in real time using a data acquisition system. The data acquisition system includes sensors (thermocouple), a terminal block, DAQ card, and analyzing software. An SWG 36 Alumal–Cromal (type K) thermocouple is used in this study which can measure temperatures from -180°C to +1,300°C. It has a high accuracy of 1.5°C on each side from -40°C to +375°C

Table 1: ultrasonic machine specifications

S.NO	DESCRIPTION	VALUES
1	INPUT POWDER	2500W
2	OUTPUT FREQUENCY	20KHZ
3	MAXIMUM AMPLITUDE	50μm
4	MAXIMUM FORCE	300N
5	STROKE LENGTH	100mm

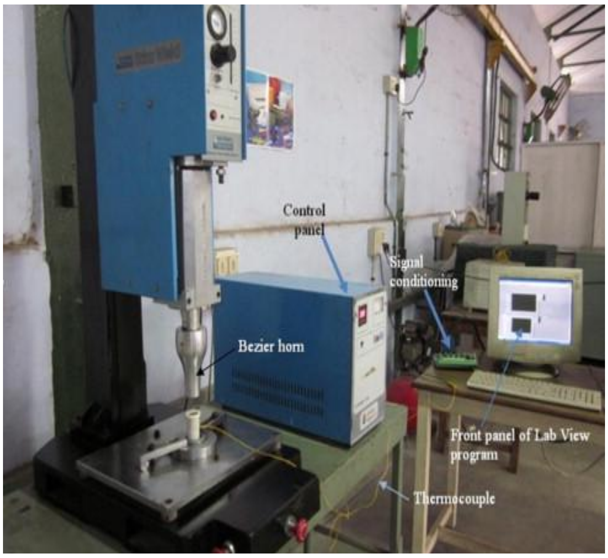


Fig 1 experimental setup

2.2 Welding Parameters

There are mainly two types of factor that affect any process one is the controlled and another is uncontrolled one. Here in the USW, the controlled factors are welding time, welding pressure, input power, frequency, amplitude etc. The uncontrolled factors are that factors which can't be controlled during process. In this paper, the uncontrolled factors were neglected and controlled factors were selected for study. It has noted that most affecting parameters were welding time, welding pressure and amplitude of sonotrode. Here all three factors were considered. Each of the factors with three levels has taken as shown in table 2. And table 3

Table 2: Factors and levels for the experiments

Factors	Level 1	Level 2	Level 3
Pressure (bar)	1.5	2	2.5
Amplitude (μm)	40	45	50
Welding Time (s)	2	2.25	2.50

Table 3: parameters and their levels of experiment

SYMBOLS	PROCESS PARAMETERS	LEVELS		
		LOW	MEDIUM	HIGH
V	Voltage (Volt)	220	230	240
I	Current (amp)	10.4	10.8	11.6
P	Pressure (MPa)	1.5	2	2.5

2.3 Heat generation

The this investigation mathematical formula is used in mechanical engineering to calculate how much heat is generating during welding process in ultrasonic welding

Table 4: heat generation during welding results

S.NO	Voltage (volts)	Current(amps)	Weld time(sec)	Heat generation(joules/mm)
1	220	10.4	2	193.734
2	220	10.8	2.25	226.525
3	220	11.6	2.50	270.332
4	230	10.4	2	202.711
5	230	10.8	2.25	236.822
6	230	11.6	2.50	282.627
7	240	10.4	2	211.525
8	240	10.8	2.25	247.118
9	240	11.6	2.50	294.665

Heat generated during welding was calculated by using equation

Q = (V x A x S)/L

Where

L=length in mm

S=weld time in sec

A-welding current in amps

V-voltage in volts

Q= joules/mm

2.4 Joint strength

In this investigation the mathematical formula is given to find the joint strength of the two different materials in ultrasonic welding process

Table 5: Experimental results

Ex. No.	Welding Pressure (bar) A	Amplitude (μm) C	Welding Time (sec) B	Response							
				Interface Temperature (°C)				Joint Strength (MPa)			
				Trials			Average	Trials			Average
				1	2	3		1	2	3	
1	1.5	40	2	105	112	106	107.66	1.58	1.80	1.87	1.75
2	1.5	45	2.25	102	106	110	106	2.09	2.31	2.22	2.21
3	1.5	50	2.50	85	98	102	95	3.32	2.60	2.24	2.72
4	2	40	2.	115	106	112	111	2.09	2.45	2.09	2.18
5	2	45	2.25	102	116	108	108.66	4.26	3.32	2.31	3.29
6	2	50	2.50	103	105	110	106	1.44	1.95	2.24	1.87
7	2.5	40	2	90	95	105	96.66	3.65	3.33	2.60	2.72
8	2.5	45	2.25	117	110	102	109.66	3.22	2.42	1.92	1.87
9	2.5	50	2.50	125	115	122	120.66	1.44	1.80	1.58	1.60

Joint strength was calculated by using equation.

Final Equation: Joint Strength = +5.39 +0.12 * A +0.088 * B +0.39 * C -0.21 * A2 -0.62 * B2 -0.073 * C2 +0.024 * A* B +0.14 * A * C -0.39 * B * C

III. ANALYSIS OF VARIANCE (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which parameters significantly affected the process. In order to perform ANOVA, the total sum of square, SST is calculated using following formula:

$$SS_T = \sum_{i=1}^{N} y_i^2 - \text{C.F.}$$

Where, C.F. = Correction Factor

y_i= Response parameter (Welding Strength) of the i runs

N = Number of runs Value of N is considered 18 (9x2) as each specimen was tested two times.

Also, correction factor is calculated using following formula:

C.F. = T^2/N

Where, T = Total of the response (Welding Strength)

Mean Square (Variance) which is produced by dividing Sum of Square by Degree of freedom of factors. F Value, which is the ratio produced by dividing the Mean Square for the Model by the Mean Square for Error

Below Table shows the result of Analysis of Variance.

Table 6: Analysis of Variance

Symbol	Factors	Degree of Freedom	Sum of Square	Mean Square	F Ratio	% Contribution
A	Amplitude	2	117.5022	58.751	95.304	32.32%
B	Pressure	2	62.8435	31.422	50.971	17.28%
C	Time	2	111.5897	55.795	90.508	30.69%
D	Thickness	2	66.1028	33.051	53.615	18.18%
	Error	9	5.548	0.616		1.53%
	Total	17	363.5864	21.387		100.00%

From the ANOVA results it was observed that Amplitude and time are the most significant factors affecting the ultrasonic welding of ABS and HDPE. The percentage contribution for both Amplitude and time are 32.32% and 30.69% respectively. Thus, it can be concluded that Amplitude and time are the statistically significant parameter.

3.1 Response surface methodology

This paper focuses on the development of an effective methodology to determine the optimum welding conditions that maximize the strength of joints produced by ultrasonic welding using response surface methodology (RSM). RSM is utilized to create an efficient analytical model for welding strength in terms of welding parameters namely pressure, weld time, and amplitude.

3.2. ANALYSIS OF BONDING STRENGTH:

The analysis of each controllable factor is studied and the main effect of the same is obtained in table. Main effect of each factor at individual level i.e. at low, medium and high level is equal to the mean of strength of all experiments with the factor at individual level. The experimental results from table 4 helps to find the effect different parameters on strength at various levels

Table 7: Consolidated design of experiment table

EXPERIMENT NO	Voltage (v)	Current (amp)	Pressure (MPa)	Strength (10^6 N/m^2)
1	220	10.4	1.5	1.75
2	220	10.8	2	2.21
3	220	11.6	2.5	2.72
4	230	10.4	1.5	2.18
5	230	10.8	2	3.29
6	230	11.6	2.5	1.87
7	240	10.4	1.5	2.72
8	240	10.8	2	1.87
9	240	11.6	2.5	1.60

(a) The main effect of voltage on strength at various levels calculated as follows

L = (1.75+2.21+2.72)/3 =2.22 (10^6N/m^2)
M = (2.18+3.29+1.87)/3 =2.44 (10^6N/m^2)
H = (2.72+1.87+1.60)/3 =2.06 (10^6N/m^2)

(b)The main effect of current on strength at various levels calculated as follows

L = (1.75+2.18+2.72)/3 =2.21 (10^6N/m^2)
M = (2.21+3.29+1.87)/3 =2.45(10^6N/m^2)
H = (2.72+1.87+1.60)/3 = 2.06(10^6N/m^2)

(c) The main effect of pressure on strength at various levels calculated as follows

L = (1.75+3.29+1.60)/3 = 2.21 (10^6N/m^2)
M = (2.21+1.87+2.72)/3 = 2.26(10^6N/m^2)
H = (2.72+2.18+1.87)/3 =2.25(10^6N/m^2)

Table 8: Responses for strength

Symbols	Controlled factors	Strength(10^6N/m^2)		
		Low	Medium	High
V	Voltage	2.39	**2.44**	2.06
I	Current	2.21	**2.45**	2.43
P	Power	2.21	**2.26**	2.25

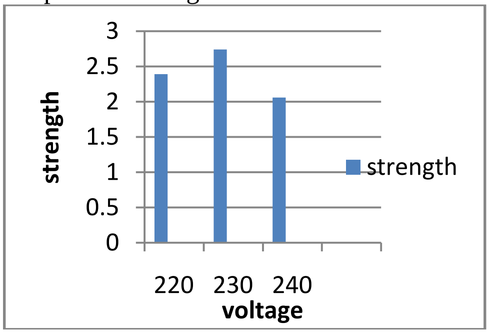
The value obtained from the response table are plotted to visualize the effect of three parameters. From the means response graph observation finding are illustrated as follows-

(a) Level III for voltage (V2) =2.44(10^6N/m^2) indicated as the optimum situation in terms of strength.

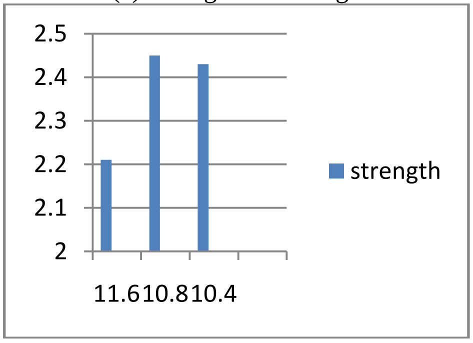
(b) Level II for current (I2) =2.45(10^6N/m^2) indicated as the optimum situation in terms of strength.

(c) Level III for voltage (P2) =2.26(10^6N/m^2) indicated as the optimum situation in terms of strength.

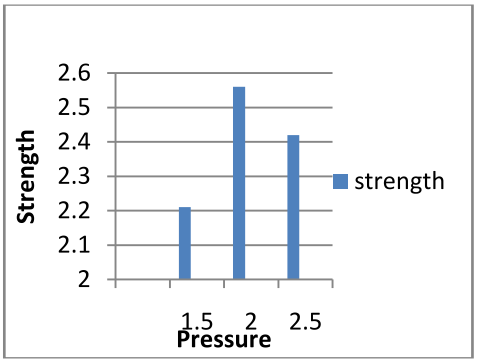
Main effect plot for Strength



(a) Strength v/s voltage



(b) Strength v/s Current



(c) Strength v/s pressure

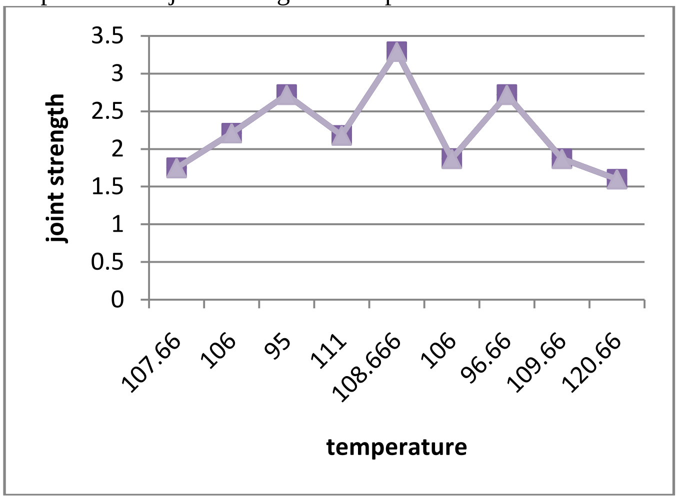
Confirmation of experiment

For maximum strength the combination of optimum parameters (V2, I2, P2).It means high voltage, medium current and high pressure. For this combination V2=230v, I2=10.8 amp and P2= 2 MPa, the strength is 3.29 (10^6N/m^2)

IV. RESULT AND DISCUSSION

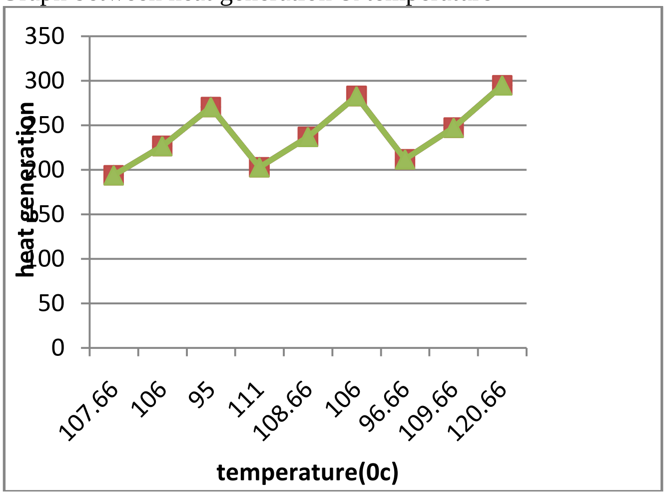
Identified 9 runs. The two materials ABS and HDPE materials are welded by using ultrasonic plastic welding machine with different parameter are taken in this process. The ultrasonic energy melts the point contact between the parts, creating a joint to experiment, using center composite technique of response surface method designs of experiment have performed and corresponding joint strength have recorded. The data acquisition system includes sensors (thermocouple), a terminal block, DAQ card, and analyzing software. Thermocouple is used in this study which can measure temperatures. In the field of mechanical engineering, while working with heat transfer, sometimes it's important to analyze welding heat to finish a particular job. The above formula is useful to find the heat generation during welding

Graph between joint strength & temperature



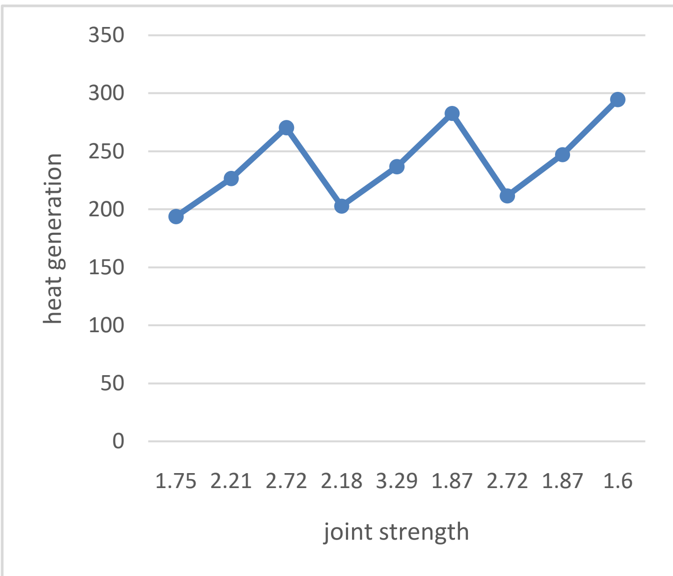
In this investigation weld at 2 bar weld pressure, 2.50 sec weld time and amplitude 45 welding strength is maximum at 3.29(10^6N/m^2).while compare to others weld strengths hence these parameters are preferable for this process. From the a above results the welding strength is maximum at temperature 108.660c and heat is generated at that welding point is 236.822 j/mm it is the optimum condition for better weld strength while compare to others. Beyond 2 bar, the weld strength again start decreasing for constant value of amplitude and weld time. This is because increase in pressure reduces the relative motion between surfaces and that leads to reduced area of contact and so reduced strength.

Graph between heat generation & temperature



Variation of heat generation with temperature welding strength is maximum at 108.66oc and the heat generation at this temperature is 236.822j/mm the heat generation is depend up on the temperature. Results of present investigation have been valuable to choose ideal welding condition, at which the most extreme weld quality can accomplish to enhance weld capacity of ABS & HDPE material.

Graph between heat generation & joint strength



Variation of heat generation with joint strength has been shown in the above figure. It is observed that at joint strength 3.29 Mpa and heat generation 236.822 J/mm is the optimum condition if the strength raised above that material will be melted lower than that the strength will be low

Modeling of experimental data of joint strength

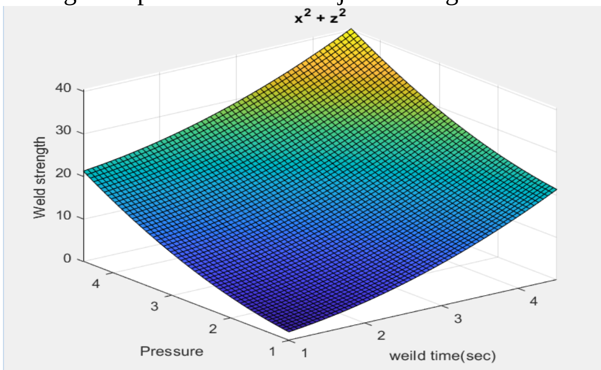


Fig (a) Response surface, Effect of pressure and weld time on weld strength

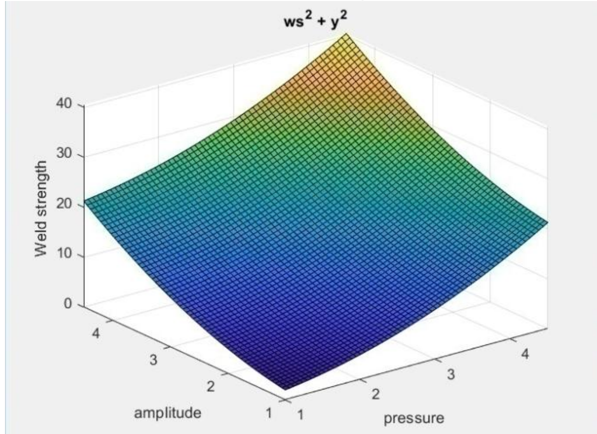


Fig (b) Response surface, Effect of amplitude and pressure on weld strength

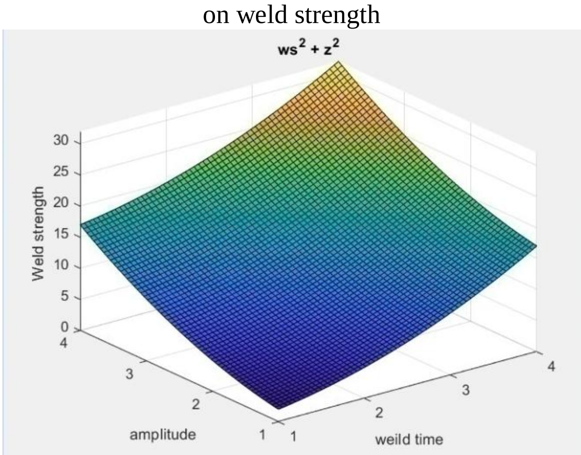


Fig (c) Response surface, Effect of amplitude and weld time on weld strength

From fig (a) (b) (c) shows the 3D response surface effect of different parameters on weld strength .these figures also shows that the joint strength is depend upon amplitude, weld time and pressure with experiment data

MODELLING OF PARAMETERS

To generalize the result, the modeling of input parameters (Voltage, Current and Pressure) and output parameters (Strength) is done using REGRESSION MODELING and Mat lab software R2011b. Now the Formula of strength in terms of voltage, Current, and Pressure

Strength = $(\text{Voltage})^{0.5514} * (\text{Current})^{0.1431} * (\text{Pressure})^{1.5115}$

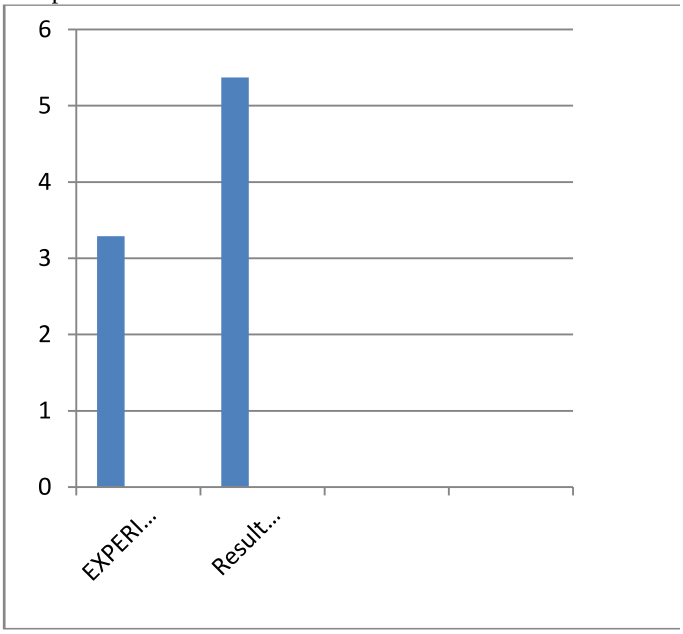
Table 9: Experimental results & Result from Mathematical modeling

Strength	
Experimental result	Result from mathematical modeling
1.75	2.86
2.21	3.77
3.22	4.30
2.18	4.57
3.29	**5.37**
2.76	5.01
2.72	3.81
1.87	5.28
1.60	2.67

Comparison of result for maximum strength
Strength = $(220)^{0.5514} * (10.4)^{0.1431} * (1.5)^{1.5115} = 2.86$
Similarly remaining strength was calculated in mathematical modelling

RESULTS	Experimental result	Result from mathematical modeling
LEVEL	V2I2P2	V2I2P2
STRENGTH($10^6 N/m^2$)	3.29	5.37

Comparison of results



From the graph is between experimental results and results from mathematical modeling from this results the weld strength is maximum at V2I2P2

V. CONCLUSION

- Experimental and analytical thermal analysis on ultrasonic welding process parameter improvement have been performed on Acryl nitride Butadiene-Styrene (ABS) and High Density Polyethylene (HDPE)
- In this study, RESPONSE SURFACE METHODOLOGY (RSM) has revalidated to predict the most weld strength of welds created by USW
- From the outcomes, it was discovered that the welding strength mainly depends on value of amplitude and then on amount of weld pressure also weld time
- Beyond 2 bar, the weld strength again start decreasing for constant value of amplitude and weld time. This is because increase in pressure reduces the relative motion between surfaces and that leads to reduced area of contact and so reduced strength.
- Optimized weld strength has observed to be maximum 3.29 MPa at 2 bar weld pressure; 2.50 sec weld time and amplitude of 45μm. Results of present investigation have been valuable to choose ideal welding condition, at which the most extreme weld quality can accomplish to enhance weld capacity of nonmetallic material and rate of creation.
- From the a above results we observed that welding strength is is maximum at temperature 108.66^{0c} and heat is generated at that welding point is 236.822 j/mm

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