Experimental Investigation on Effect of Sonotrode Profile and Process Parameters on Mechanical Strength of PTFE Weld by USW

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Abstract: Ultrasonic plastic welding has received sense full attention in the past few years, and has become more suitable for wide range of applications. There are lots of advantages of ultrasonic plastic welding. The main element of equipment's that use the effects of ultrasound for welding is the ultrasonic horn (sonotrode). The performance of ultrasonic equipment depends on properly design of sonotrode profile. For proper concentration of ultrasonic energy across work piece surface during welding geometry of horn place vital role. A horn profile is directly affected to welding strength in ultrasonic welding parameters like amplitude, pressure, thickness, and time and, Sonotrode Profile also affected to the strength. The fundamental aspect of this study is to design welding horn. Design of different sonotrode profile is created in the card software and fabricated from EN24 Steel. The main objectives of this research work are to investigate the effect of different sonotrode profile and ultrasonic process parameters (amplitude, pressure, and Thickness ratio) on mechanical properties of PTFE (Ploy tetra fluoro ethylene) material, using the D.O.E. methodology.

Index Terms **- Sonotrode Design, Ultrasonic PTFE Welding, Tensile Strength,**

I. INTRODUCTION

One of the most generally utilized welding strategies for joining thermoplastics uses Ultrasonic energy. Ultrasonic welding has existed since the mid-1950s. Ultrasonic is an elasto-mechanical vibration with a frequency of 20000-40000 cycles for every second that is over the human hearing limit. A current was induced in this Magnetostrictive material, which create a periodic alternating magnetic field, accordingly causing a dimensional change in the material. Today however, ultrasonic welders created motions through piezoelectric ceramics. Re-arrangement of dipoles inside the basic cells of the piezoelectric ceramics causes an incremental change in volume. This modification of dipoles is the actuation that progressions electrical energy to mechanical vibrations. [1], [2]

II. ULTRASONIC WELDING SETUP

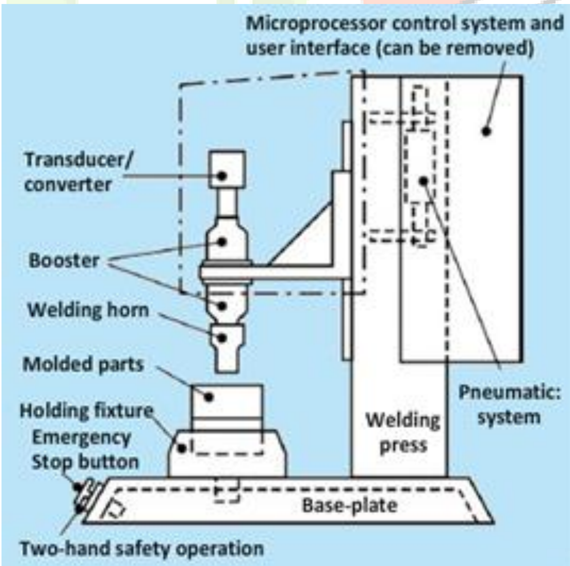

Fig 1.1 Ultrasonic Welding Set -Up[2]

The kind of device required to create a completely working set-up are contrasts for various applications, but the segments are generally divided to five principle segments. The first is the power supply or known as generator where it supplies the essential current and voltage. The second is the converter which changes over electrical energy to the mechanical vibratory energy. The third constituent is booster where it changes the amplitude of the vibrations and transmits to the fourth segment which is horn to transmit vibratory energy to the part to be welded. This part will be hold by the last segment of ultrasonic welder which is holding Fixture.[2]

2.1 Power Supply

The power supply or generator changes over the low voltage electrical energy with frequency run inside 50-60 Hz into a desired high voltage signal regularly at 20-40 kHz. There is much sort of energy supplies with fluctuating levels of process control which is from essential to microprocessor controlled units. The output power control ranges are 100 to 6000 W.[4]

2.2 Converter

The converter/transducer changes over the electrical energy create from the generator to the mechanical vibrations. The frequency range of the vibration can be in the range of 15 – 70 kHz; however the regular frequency used as a part of ultrasonic welding inside 20 to 40 kHz.[4], [5]

2.3 Booster

The booster is a section that situated between the converters to join the mechanical vibrations from the converter to the horn. The purpose of the booster is to increase the mechanical vibrations at the tip of the converter and further more to give a developing position to affix the welding stack (converter, booster and horn) to the actuator.[3], [6]

2.4 Horn

The welding horn or known as sonotrode is an instrument that transmits the mechanical vibrations to the specimens. It is specially made to run well with the necessities of the application and parts being welded. Good horn configuration gives an effective and great quality welding. Only specialist who is adept in acoustical design can be made an exact and great horn design. Horn material that usually utilized is high strength aluminum alloy, titanium or solidified steel.[7], [8]

III. SONOTRODE DESIGN

A sonotrode, also known as horn, Acoustic Amplifier and, Velocity Transformer that transfer the mechanical vibrations from booster to work piece. The molecules of a horn expand and contract longitudinally along its length so the horn expands and contracts at the frequency of vibration. [9], [10], [11], [12]

3.1 Sonotrode Design

Sonotrode works on principle which states when sound wave passes through a medium sound velocity increases with decrease in cross-sectional area of the medium. Thus, from above statement it obvious that Sonotrode are having different areas at two ends i.e. exit area is made smaller than the entry area. It is designed on the basis of elastic vibration of an elastic member with varying cross-section. For design of Conical and Exponential sonotrode used CARD (Computer Aided Resonator Design) Software. [12], [13]

Table 3.1 Input Parameter of CARD

Sr. No.	Parameter	Value
1	Material	EN24(AISI4340)
2	Thin Wire Wave Speed	5334 m/sec
3	Modulus of Elasticity	210 Gpa
4	Density	7850 Kg/m^3
5	Input Frequency	20000 Hz
6	Big End Diameter	40 mm (Conical)
		30 mm (Exponential)
7	Small End Diameter	5 mm (Conical)
		6 mm (Exponential)
8	Input Resonator Length	150 mm (Conical)
		151.8 (Exponential)

Table 3.2 Output from CARD

Parameter	Dimension by CARD
Output for Conical Sonotrode	
Length	150 mm
Transformation Ratio	3.41
Output for Exponential Sonotrode	
Length	148.6
Transformation Ratio	4.85

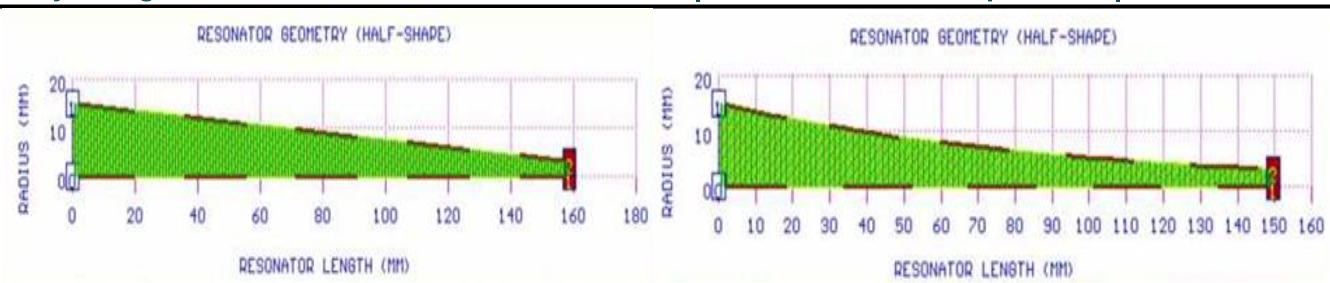

Fig 3.1 Illustrate Conical Shaped Sonotrode Design and Exponential Shaped Sonotrode Design

Fig 3.2 Fabricated Conical Sonotrode and Exponential Sonotrode

IV. EXPERIMENTAL WORK

4.1 Material Selection

In this research use Polytetrafluoroethylene (PTFE, Teflon) as a work piece material. PTFE is a fluorocarbon solid, as it is a high-molecular-weight compound consisting wholly of carbon and fluorine. PTFE is hydrophobic: neither water nor water-containing substances wet PTFE, as fluorocarbons demonstrate mitigated London dispersion forces due to the high electronegativity of fluorine. PTFE has one of the lowest coefficients of friction of any solid.

Table 4.1 Properties of PTFE Material

Property	Value
Density	2200Kg/m^3
Melting Point	600k
Young's Modulus	0.5Gpa
Yield Strength	23Mpa
Coefficient of Friction	0.05-0.10

4.2 Levels and Process parameter

In ultrasonic welding there are different parameters that affect the welding Strength like, Amplitude, Pressure, Thickness Ratio, Sonotrode Profile, Welding Time and, Holding Time, Welding Material etc. For this research work we decide four variable parameters, and two constant variables. [14], [15]

Table 4.2 Constant Parameters

Parameters	Variables
Welding Time	3 sec
Holding Time	3 sec

Table 4.3 Levels and Parameters

Parameter	Level 1	Level 2	Level 3
Amplitude	70	80	90
Pressure	4	5	6
Sonotrode Profile	Conical	Exponential	---
Thickness Ratio	2	3	2-3

4.3 Full Factorial Design

We have four parameter and three levels, so we used Full factorial design for experiment. These run order we obtain from MINITAB 18.

Table 4.4 Full Factorial Run Order

Run Order	Amplitude	Pressure	Thickness Ratio	Sonotrode
1	70	6	2	Conical
2	70	5	3	Exponential
3	90	6	3	Exponential
4	90	6	2-3	Conical
5	70	4	2	Exponential
6	80	5	2	Conical
7	70	5	2	Conical
8	80	5	2	Exponential
9	70	4	3	Exponential
10	70	4	2-3	Exponential
11	90	6	2-3	Exponential
12	70	6	3	Exponential
13	80	6	2-3	Conical
14	90	6	3	Conical
15	80	5	2-3	Exponential
16	90	5	3	Conical
17	90	5	2-3	Exponential
18	80	6	2	Conical
19	80	6	3	Conical
20	80	5	3	Exponential
21	90	5	2	Conical
22	90	6	2	Conical
23	90	4	2	Conical
24	70	5	2-3	Conical
25	80	4	3	Conical
26	80	5	3	Conical
27	80	4	2	Exponential
28	90	4	2-3	Exponential
29	70	6	2-3	Conical
30	70	4	2	Conical
31	70	4	3	Conical
32	80	6	2-3	Exponential
33	70	5	3	Conical
34	80	6	2	Exponential
35	90	6	2	Exponential
36	90	5	3	Exponential
37	70	6	2-3	Exponential
38	90	4	3	Exponential
39	90	5	2	Exponential
40	90	4	2	Exponential
41	70	5	2-3	Exponential
42	90	4	3	Conical
43	80	5	2-3	Conical
44	70	6	3	Conical
45	80	4	3	Exponential
46	90	5	2-3	Conical
47	80	4	2-3	Exponential
48	70	5	2	Exponential
49	90	4	2-3	Conical
50	80	6	3	Exponential
51	80	4	2	Conical
52	70	4	2-3	Conical
53	70	6	2	Exponential
54	80	4	2-3	Conical

4.4 Experiment and Testing

From the Different parameter and level Weld the PTFE Material on Ultrasonic Welding Machine.

Fig.4.1 Welding Strips of PTFE Material

After the Welding of PTFE strips Checking the tensile strength of the PTFE strips. Universal testing machine is used to check the Tensile strength of the Material.

Fig.4.2 After the Testing of PTFE Strips

Table 4.5 Tensile Testing of PTFE Strips

Run Order	Amplitude (micron)	Pressure (bar)	TR (mm)	Sonotrode	Strength (Mpa)
1	70	6	2	Conical	10.7156
2	70	5	3	Exponential	8.2032
3	90	6	3	Exponential	10.9343
4	90	6	2-3	Conical	11.2441
5	70	4	2	Exponential	9.5879
6	80	5	2	Conical	11.4506
7	70	5	2	Conical	10.7583
8	80	5	2	Exponential	11.3141
9	70	4	3	Exponential	8.0138
10	70	4	2-3	Exponential	9.4233
11	90	6	2-3	Exponential	10.8710
12	70	6	3	Exponential	8.6137
13	80	6	2-3	Conical	10.5188
14	90	6	3	Conical	11.7613
15	80	5	2-3	Exponential	10.2092
16	90	5	3	Conical	10.7595
17	90	5	2-3	Exponential	10.8366
18	80	6	2	Conical	11.6097
19	80	6	3	Conical	9.4243
20	80	5	3	Exponential	9.1322
21	90	5	2	Conical	13.3477
22	**90**	**6**	**2**	**Conical**	**14.3454**
23	90	4	2	Conical	12.8747
24	70	5	2-3	Conical	9.7338

25	80	4	3	Conical	8.9187
26	80	5	3	Conical	9.1955
27	80	4	2	Exponential	10.9590
28	90	4	2-3	Exponential	10.5190
29	70	6	2-3	Conical	10.1343
30	70	4	2	Conical	10.1509
31	70	4	3	Conical	8.2861
32	80	6	2-3	Exponential	10.2863
33	70	5	3	Conical	8.5290
34	80	6	2	Exponential	11.4431
35	90	6	2	Exponential	13.4625
36	90	5	3	Exponential	10.6029
37	70	6	2-3	Exponential	9.9751
38	90	4	3	Exponential	10.0323
39	90	5	2	Exponential	12.7129
40	90	4	2	Exponential	12.1334
41	70	5	2-3	Exponential	9.5131
42	90	4	3	Conical	10.2789
43	80	5	2-3	Conical	10.3183
44	70	6	3	Conical	8.7137
45	80	4	3	Exponential	8.9538
46	90	5	2-3	Conical	10.8917
47	80	4	2-3	Exponential	10.0438
48	70	5	2	Exponential	10.7077
49	90	4	2-3	Conical	10.7617
50	80	6	3	Exponential	9.2348
51	80	4	2	Conical	11.1671
52	70	4	2-3	Conical	9.5326
53	70	6	2	Exponential	10.5031
54	80	4	2-3	Conical	10.2900

V. ANALYSIS OF VARIANNCE

Table 5.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sonotrode	1	1.039	1.0390	6.77	0.012
TR	2	44.372	22.1862	144.62	0.000
Pressure	2	3.915	1.9574	12.76	0.000
Amplitude	2	39.621	19.8103	129.13	0.000
Error	46	7.057	0.1534		
Total	53	96.004			

Table 5.2 Model Summery

S	R-sq	R-sq(adj)	R-sq(pred)
0.391680	92.65%	91.53%	89.87%

Figure clearly suggests a dominant influence, in a quantitative sense, of the Welding Pressure, Amplitude, Sonotrode Profile The result of ANOVA represented in response diagrams shown in Figure suggest that the optimal combination of welding parameter levels, which gives the highest value of the tensile strength A3 P3 T1 Conical.

Residual plots are used to evaluate the data for the problems like non normality, nonrandom variation, non-constant variance, higher-order relationships, and outliers. It can be seen from that the residuals follow an approximately straight line in normal probability plot. Histogram is the special case because skewed-right data have a few large values that drive the mean upward but do not affect where the exact middle of the data is (that is, the median). Residuals possess constant variance as they are scattered randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

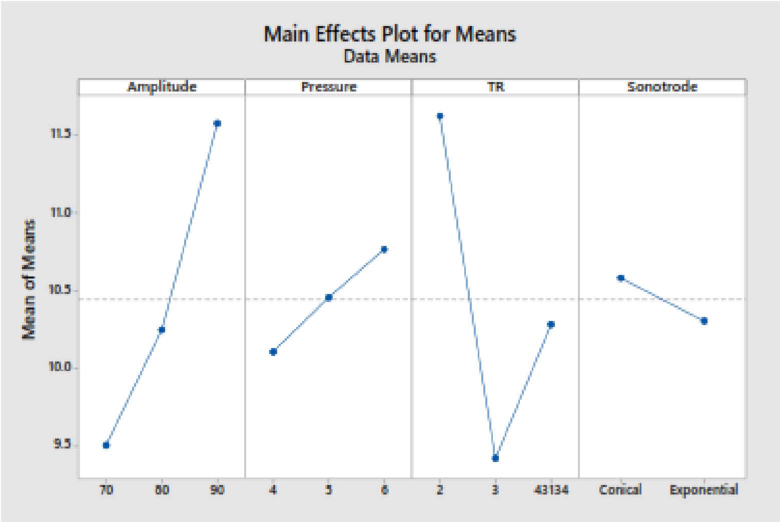

Fig.5.1 Main Effect plot for Means

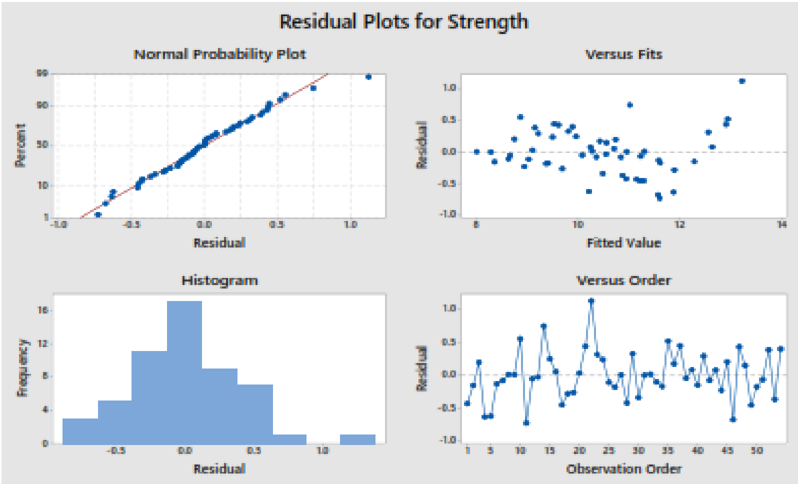

Fig.5.2 Residual Plots for Strength

VI. CONCLUSION

During experimentation work there was lots of problem occurred due to improper tuning of sonotrode. Several times experiments fail due to improper tuning of sonotrode.

Welding done through conical horn gives the better tensile strength then exponential horn. From ANNOVA we got the best combination of parameters is amplitude 90 micron, Pressure 6 Bar, Thickness ratio 2 and conical shape horn gives the better tensile strength. Strength of the best combination is 14. 345437003175594 N.

Whenever increase the Thickness ratio that's time Strength was very less.

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