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Optimization of Process Parameters in Resistance Welding of Cast Acrylic Plates using Taguchi Method and Genetic Algorithm

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***Abstract*— In industrial and day to day usage, thermoplastic polymers are replacing many conventional materials and gained attention. Resistance welding (RW) is most commonly used method for joining of thermoplastic. The objective of this welding process is to understand the different properties of weld joints. The thermoplastic material used in this investigation was cast acrylic which finds applications in automotive industry, aerospace, medical, outdoors and optical areas. The main process parameters that govern the welding process are current, pressure and time. In resistance Welding, joining of parent material takes place by keeping a conductive interlayer between the joined parts. The stainless steel wire mesh is a non corrosive and conductive interlayer. The numbers of experiments are designed on the basis of Taguchi L_9 orthogonal array and process parameters are optimized by genetic algorithm and also by Taguchi method because of their simplicity, ease of operation, time reducing and cost effective experimental design. The joints are produced and the strength of the welded joints is mechanically evaluated based on the tensile shear strength and hardness. The joints are also analyzed microscopically which shows that whether wire mesh give good joints or not. The optimum combination of parameters for maximum tensile shear strength and for maximum hardness was Current 40 A, Pressure 2.94 MPa and time 30 second respectively.**

***Index Terms*— RW, Current, Pressure, Time, Microstructure**

I. INTRODUCTION

Nowadays, polymers are extensively used in many application areas like construction, aerospace, automobile industries etc. due to their inherent superior properties [1]. In the case where thermoplastic composites are to be joined, fusion bonding or welding is an alternative joining method [2]. Various welding techniques are available for joining of thermoplastic composites.

Generally the methods those generated heat at the weld interface, are usually classified into three main categories friction welding, thermal welding and electromagnetic welding. Among different electromagnetic welding techniques, resistance welding was the focus of many investigations in the last decade because of its simplicity [3] [4]. From the past literatures there are some publications find out for joining of different thermoplastic materials by resistance welding but cast acrylic materials was not joined earlier by this welding methods. In this paper an investigation in joining of cast acrylic plates by resistance welding was carried out. The main objective of this work is to evaluate the behavior of weld joints by mechanical and metallurgical studies. The suitable process parameters used for joining are current; pressure and time for getting the desired mechanical properties such as tensile shear strength and hardness of the joints. The optimization of process parameters was analyzed by Taguchi orthogonal array and genetic algorithm. To validate the experimental results statistical analysis were conducted to draw meaningful conclusions. The statistical analysis was conducted using Minitab 16 and Matlab 10. The factors considered were current, pressure and time and the response were tensile shear strength and hardness. All the parameters are considered at three levels.

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A. Resistance welding process

Resistance welding has been identified as being one of the most promising techniques for joining thermoplastic composites [5]. It offers a number of advantages compared with other joining methods: unlike mechanical fastening it creates a uniform joint with no stress concentration and no damage or distortion induced to the fibers; unlike adhesive bonding it requires little or no surface preparation. It is a fast, inexpensive technique that requires simple, low-cost equipment, which could be made portable for repair purposes [6]. It also offers a possibility of reprocessing if flaws or defects were detected at the joint interface [7] [8]. Moreover, resistance welding can be applied to weld large components [9]. It has been applied to complicated joints in automotive applications, plastic pipes [10], containers and medical devices [11], and more recently, aerospace applications. The working principle of the resistance welding process is rather simple. The heat is provided by an electrically resistive implant, also called the heating element, which is trapped between the parts to be joined, under the application of pressure. When electrical current passes through the heating element, heat is generated due to Joule's heating effect. The temperature increases at the interface between the two parts, and the polymer surrounding the heating element starts to melt. When nominal melting is achieved, the current is stopped and the joint is allowed to cool while the pressure is maintained, until it solidifies and form the weld. The heating element remains trapped in the joint, allowing reprocessing by applying electrical current again. However, its presence in the joint might affect the strength of the structure, so compatibility with the joint material is critical [12]. The heating element plays an important role in resistance welding. Carbon fibers and stainless steel metal meshes are used as heating element. Carbon Fiber (CF) prepreg can be used as a heating element; however the fiber breakage may lead to uneven current distribution across the width of heating element. Compared to carbon fiber, stainless steel mesh is more advantageous. In the case of stainless steel meshing, air entrapment between the wires is less [13].

B. *Taguchi methodology*

Taguchi method is a powerful tool for the design of a high quality system. It provides a systematic approach to design optimization for performance and quality. Further, Taguchi parameter design can optimize the performance through the settings of design parameters and to reduce the fluctuation of system performance [14] [15]. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the overall loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, *i.e.* the lower-the-better, the larger-the-better, and the nominal-is-best. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio.A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameters with only a small number of experiments. A loss function is then defined to calculate the deviation between the experimental value and the desired value. The quality characteristic to determine the tensile shear strength and hardness was represented as follows.

S/N ratio (η) = $-10\log [(1/n) (\Sigma (1/Y^2)]$

Where, η is quality characteristic; n = number of replications and Y is the experimental observations.

ANOVA is performed on the 'S/N ratios' and this ANOVA table helps to find the contribution of process parameters on the output and shows that which is the best optimal levels of parameters.

C. *Genetic Algorithm*

GA is a computerized search and optimization algorithm based on the mechanics of natural genetics and natural selection. GA is very different from traditional search and optimization method used in engineering problems. Because of its simplicity, ease of operation, minimum requirements, and global perspective, GA has been successfully used in a wide variety of problems [16] [17] [18]. Genetic algorithm is a random search method. Artificial individual is the basic element of the genetic algorithm. The function optimization, the maximum or minimum is found which is based on the variation of x1, x2, x3…xn beginning with one or more starting points [19].

II. METHODS

A. *Material and heating element*

The material used for specimen was cast acrylic plates of size thickness as 10 mm, length as 100 mm and width as 50 mm. Cast Acrylic is a material with unique physical properties and performance characteristics. Its weight is half of the fine optical glass and is up to 17 times more impact resistance. Cast acrylic sheet response to temperature changes by expanding and contracting faster than glass and also more flexible than glass and other material.

The heating element plays the key role in the process of resistance welding. It supplies the necessary welding energy to the joint and is one of the main contributors to the joint quality. The heating element used was stainless steel because it produces welds with better consistency and higher average strength and the in this heating element air entrapment between wire is less. Its dimensions are of size length as 200 mm and width as 25 mm.

B. *Properties of the materials*

The properties of cast acrylic materials was shown in the Table 1

Table 1: Properties

S. No.	Properties	Cast Acrylic
1	Tensile strength (ASTM D638-10)	46-76 MPa
2	Hardness (ASTM D785-10)	85-105 HR
3	Thermal conductivity	0.167-0.25
4	Melting temperature	85-160 ^{0}C

C. *Process parameters and experimental design*

The process parameters used in this resistance welding process was current (Amperes), pressure (MPa) and time (s) and these parameters are used up to three different levels to determine the tensile shear strength and hardness of the joints respectively. The process parameters with their levels generate the design for experiments by selecting L_9 orthogonal array. The process parameters and orthogonal array with three levels are shown in Table 2 and Table 3.

Table 2: Parameters and Levels

Process Parameters	Level 1	Level 2	Level 3

A (current) (Amperes)	20	40	60
B (pressure) (MPa)	0.98	2.94	4.90
C (time) (s)	10	20	30

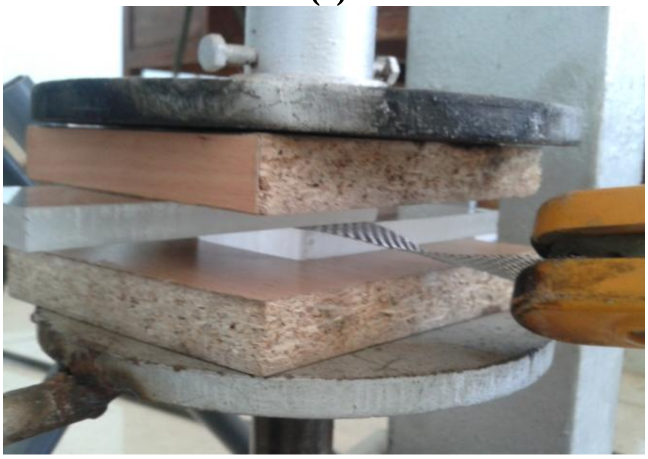
Table 3: L_9 Orthogonal array

Exp. run	A (current) (Amperes)	B (pressure) (MPa)	C (time) (s)
1	20	0.98	10
2	20	2.94	20
3	20	4.90	30
4	40	0.98	20
5	40	2.94	30
6	40	4.90	10
7	60	0.98	30
8	60	2.94	10
9	60	4.90	20

D. Experiments and machine set-up

The machine set up consists of space to plates, space adjusting wheel etc. and a pressure gauge to measure the accurate pressure during the process. It has a hydraulic jack to pressure applied. In this process the number ofexperimental run performed was nine according to the L_9 orthogonal array employed to carry out the design of experiment. First place the stainless steel wire mesh and then place that assembly into fabrication set up and tighten it well after checking alignment of those plates. After putting the assembly connects the positive and negative terminal of D.C. power source to both side of wire mesh. The detailed view of machine set-up was shown in Fig. 1(a) and the basic principle of the process was shown in the Fig.1 (b)Ensure before applying pressure two plates are proper aligned or not. Apply the pressure to any one of the desired side and set the current levels to any one of the desired value. After completing the joining process the weld specimens were taken for finding out the tensile shear strength and hardness of the joints respectively. The processed parameters were optimized by Taguchi method by taking S/N ratio with quality characteristic larger-the-better and also through genetic algorithm. The scanning electron microscopy is used to analyze the microstructure of the joints.

(a)



(b)

Fig. 1 Machine Set-up

III. RESULT AND DISCUSSION

A. Mechanical Testing and optimization of process parameters

The welded joints processed by resistance welding process are further goes through mechanical testing. These welded joints are investigated for properties such as tensile shear strength and hardness respectively. The tensile test was conducted for find out tensile shear strength for all welded parts on UTM (Universal Testing Machine). The hardness of the joints measured through Rockwell hardness test conducted on Rockwell hardness machine. Table 4 shows the result values after performing the all experiment run for tensile shear strength and hardness of joints along with their S/N ratio values according to the selected orthogonal array respectively. The best result for tensile shear strength was observed at the experiment run 5 in Table 4 and on the same way the hardness of the joint was also gave best result at this experiment run. The results of the processed joints were optimized by Taguchi method and genetic algorithm.

In Taguchi methodology the optimal level of process parameters was observed on the basis of large S/N ratios values in Table 3 and the optimal process parameters was current 40 amperes, pressure 2.94 MPa and time 30 s for both tensile shear strength and hardness of the joints. Table 5 shows the mean value response of tensile shear strength and hardness. Table 6 shows the analogous behavior of the predicted tensile shear strength and hardness with the experimental result using the optimal welding parameters. The variation of the S/N ratio with parameters levels for tensile shear strength and hardness was shown in Fig 2 and Fig. 3.

Table 4: **Performance characteristics with input parameters and S/N values**

Exp. run	A (current) (Amperes)	B (pressure) (MPa)	C (time) (s)	Tensile shear strength (MPa)	S/N value for tensile shear strength (Ƞ)	Hardness (HR$_L$)	S/N value for hardness (Ƞ)
1	20	0.98	10	3.26	10.26	67	36.52
2	20	2.94	20	4.96	13.90	76	37.61
3	20	4.90	30	6.27	15.94	80	38.06
4	40	0.98	20	6.53	16.29	81	38.16
5	40	2.94	30	6.79	16.63	88	38.88
6	40	4.90	10	5.57	14.91	82	38.27
7	60	0.98	30	5.70	15.11	79	37.95
8	60	2.94	10	6.53	16.29	80	38.06
9	60	4.90	20	6.27	15.94	81	38.16

Table 5: S/N Ratio response for tensile shear strength and hardness

Parameters	Tensile shear strength (MPa)			Hardness (HR$_L$)		
	Level 1 mean value	**Level 2 mean value**	**Level 3 mean value**	**Level 1 mean value**	**Level 2 mean value**	**Level 3 mean value**
A (Current) (Amperes)	4.83	6.29	6.16	74.33	83.67	80
B (Pressure) (MPa)	5.16	6.09	6.03	75.67	81.33	81
C (Time) (s)	5.12	5.92	6.25	76.33	79.33	82.33

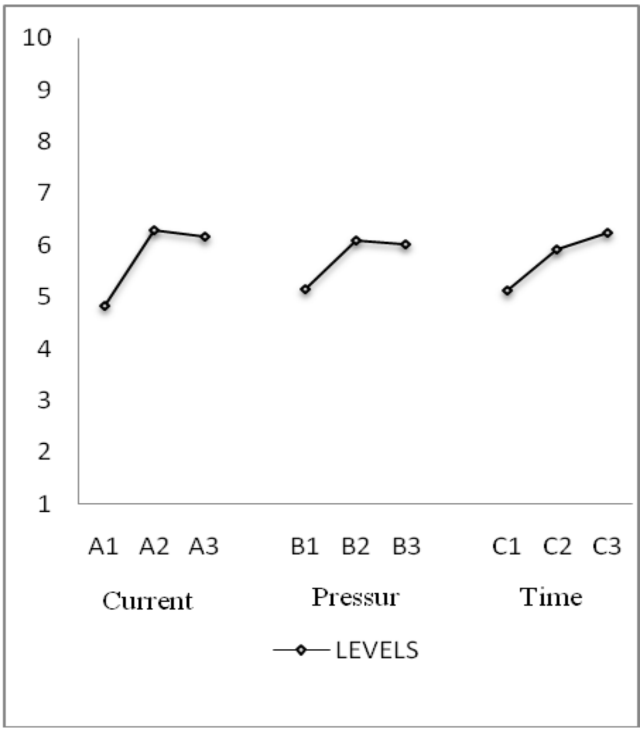


Fig. 2 S/N Ratio response graph for tensile shear strength

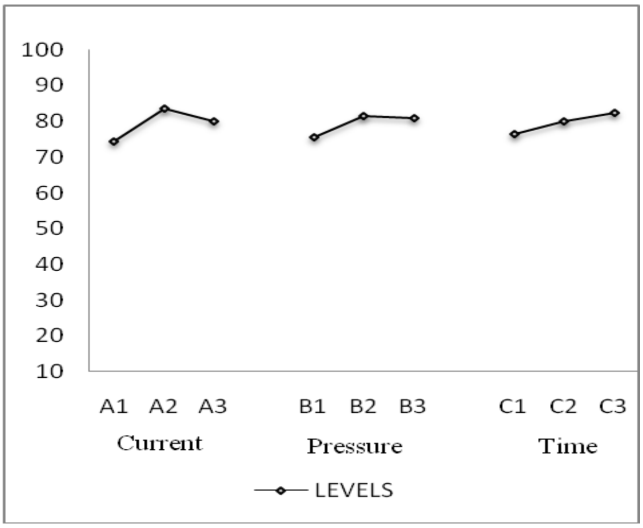


Fig. 3 S/N Ratio response graph for hardness

Table 6: Result verification and optimum levels of parameters through Taguchi method

	A (Current) (Amperes)	B (Pressure) (MPa)	C (Time) (s)	Predicted optimum tensile shear strength through Taguchi (MPa)	Predicted optimum hardness through Taguchi (HR$_L$)	Verified result for tensile shear strength (MPa)	Verified result for hardness (HR$_L$)
Optimum parameters of tensile shear strength and hardness	Level 2 (40)	Level 2 (2.94)	Level 3 (30)	7.11	88.66	6.79	88

The genetic algorithm creates a population of solutions and applies genetic operators such as mutation and crossover to evolve the solutions in order to find the best one(s). A MATLAB function was written and this function known as the input for creating fitness function for the multi objective optimization. The main objective of this optimization was i) maximize tensile shear strength ii) maximize hardness. The optimization of the welding parameters through GA is discussed below.

Objective function:
Maximize F1(x); Maximize F2(x);
Where F1(x), F2(x) = *f* (A, B, C)
F1(x) = Tensile shear strength; F2(x) = Hardness and A = Current; B = Pressure and C = Time are the process parameters lies in range $\{20 \le A \le 60; 0.98 \le B \le 4.90; 10 \le C \le 50\}$

$$F1(x) = - 2.813 + 0.1243*A - 0.0455*B + 0.528*C + 0.0168*A*B - 0.0406*B*C - 0.0079*A*C$$

$$F2(x) = 36.91 + 0.316*A + 1.732*B + 3.02*C + 0.1239*A*B - 0.357*B*C - 0.0357*A*C$$

The optimized Pareto front achieved after 128 iterations as shown in Fig.4 The two responses are found to be conflicting from the Pareto chart. The point on the Pareto set is associated with a set of decision variables. The one point solution was predicted for simultaneously optimizing the both responses. Table 7 shows the optimal value for tensile shear strength and hardness from the Pareto front.

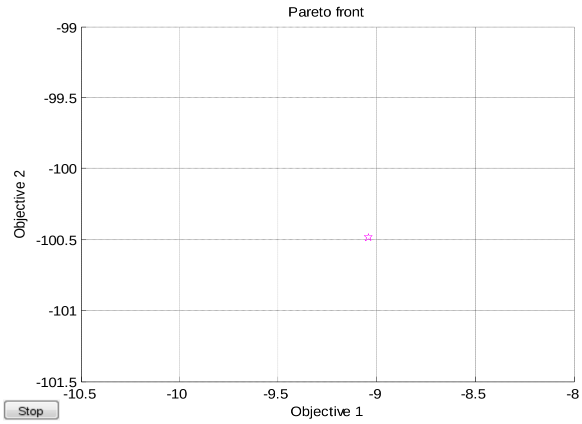


Fig.4 Pareto front plot

Table 7: Optimized result of Genetic Algorithm

	Tensile shear strength (MPa)	Hardness (HR_L)	C (current) (Amperes)	P (pressure) (MPa)	T (time) (sec)
Experimental value	8.27	97.56	26.45	0.980	29.55

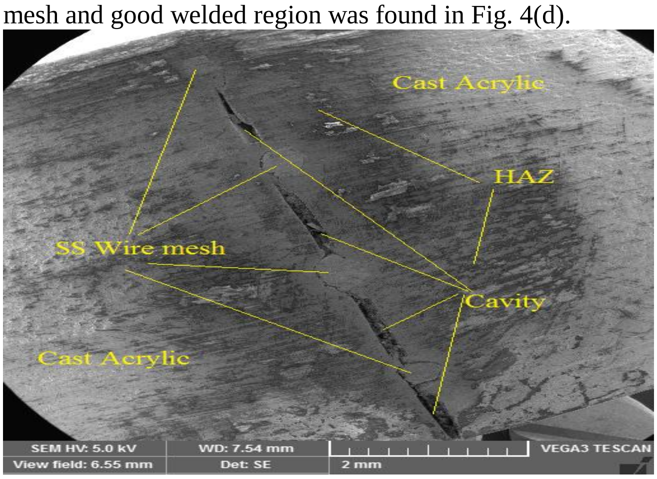
Table 8: Confirmation test

	Tensile shear strength (MPa)	Hardness (HR_L)	C (current) (Amperes)	P (pressure) (MPa)	T (time) (sec)
Genetic Algorithm	9.04	100.48	26.45	0.980	29.55

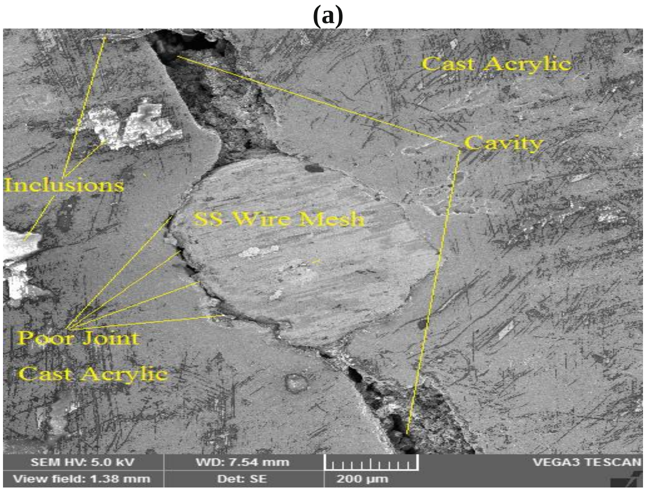
In order to verify results one confirmation test as shown in Table 8 was performed on material that is multi objective. The result obtained was compared with predicted performance. The minimum difference observed between theoretically predicted and experimentally obtained values of the tensile shear strength and hardness confirms that the applicability of the genetic algorithm.

B. SEM Observations of welded joints

Scanning electron microscopy allows higher magnification than optical microscopy to observe the strength of the welded joints at different levels of parameters. The surface to be observed were coated with a thin layer of gold-palladium with a Hummer VI sputter coater also called as sputter coating. Various regions can be identified as stainless steel wire mesh, heat affected zone, cavity, inclusions, poor joints and good joints. To investigate the welded joints quality based on results of mechanical testing two levels of parameters are considered such as lower level and higher level. Fig. 4a and Fig. 4b shows the microstructures of weld joint at lower level, the parameters of experiment run1in Table 3 was considered as lower level and it result that the quality of joint obtained was not good because the joints formation around the wire mesh is poor and there are some inclusions on parent material. Fig.4(c) and Fig.4 (d) presents the microstructures of weld joints at higher level in which the parameters of experiment run 5 in Table 3 are considered as higher level. The Fig. 4(c) presents that there is no cavity formed surrounding the wire mesh and good welded region was found in Fig. 4(d).



(a)



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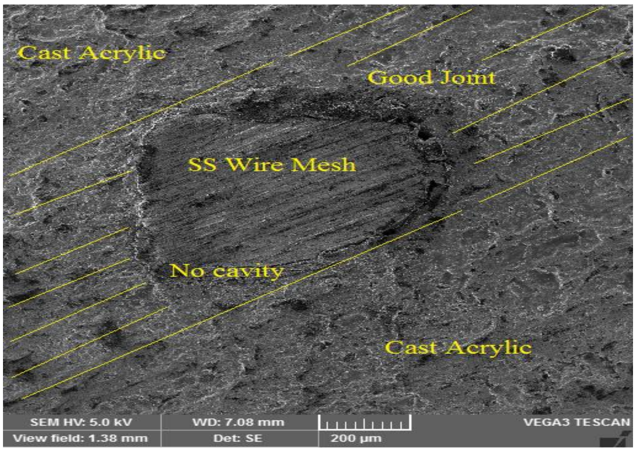
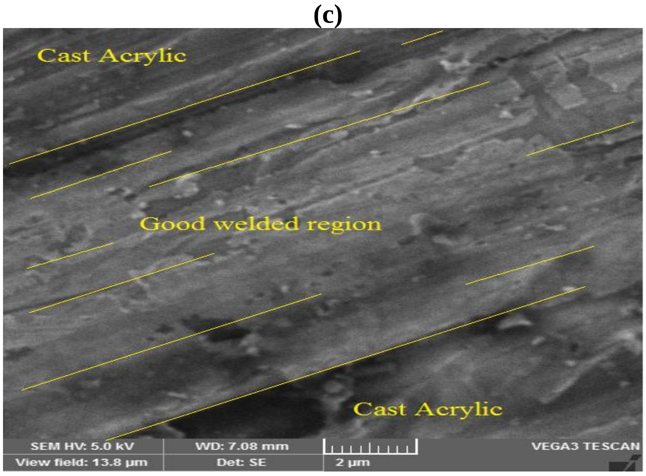


(c)



(d)

Fig. 4 SEM microstructure of welded joints

IV. CONCLUSIONS

The following conclusions can be observed form the joining of cast acrylic material by Resistance welding processs

- The cast acrylic material was joined by resistance welding process which was economical. The initial parameters in this welding process were Current, Pressure and Time.
- The Taguchi method was used to select L_9 orthogonal array which depends on the parameters and their levels.
- The maximum responses such as tensile shear strength and Rockwell hardness of joints were obtained in the optimum process parameters by means of current as 40 Amperes, Pressure as 2.94 MPa and Time as 30 s.
- The optimum parameter level at Current 40 Amperes, Pressure 2.94 MPa and Time 30 s was found using the Taguchi method which gives maximum Tensile Shear Strength of 7.11 MPa and maximum Hardness of 88.66 HR_L.
- In the optimization techniques, the mechanical responses of joints were carried out in which the maximum Tensile Shear Strength and Maximum Hardnessof joints were obtained at this combination of parameters such as Current 40 Amperes, Pressure 2.94 MPa and Time 30 s.
- The tensile shear strength and hardness of the joints are also optimized through genetic algorithm and the tensile shear strength and hardness of the joints obtained was 9.03 MPa and 100.48 HR_L at process parameters having current 26.45 Amperes, pressure 0.980 MPa and time 29.55 s.

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