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Process Parameters Optimization for Pulsed TIG Welding of 70/30 Cu-Ni Alloy Welds Using Taguchi Technique

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***Abstract*—**Taguchi approach was applied to determine the most influential control factors which will yield better tensile strength of the joints of pulse TIG welded 70/30 Cu-Ni alloy. In order to evaluate the effect of process parameters such as pulse frequency, peak current, base current and welding speed on tensile strength of Pulsed current TIG welded 70/30 Cu-Ni alloy of 5 mm thickness, Taguchi parametric design and optimization approach was used. Through the Taguchi parametric design approach, the optimum levels of process parameters were determined at 95% confidence level. The results indicate that the Pulse frequency, peak current, welding speed and base current are the significant parameters in deciding the tensile strength of the joint. The predicted optimal values of tensile strength of Pulsed current Gas tungsten arc welding (PC GTAW) of 70/30 Cu-Ni alloy welds are 368.8MPa**.**

Keywords*—*70/30 Cu-Ni alloy, pulsed current GTAW, mechanical properties, Taguchi technique, analysis of variance.

I. Introduction

FUSION welding generally involves joining of metals by application of heat for melting of metals to be joined. Almost all the conventional arc welding processes offers high heat input, which in turn leads to various problems such as burn-through or melt through, distortion, porosity, buckling, grain coarsening and joint gap variation during welding etc. Use of the proper welding process, procedure and technique is one tool to address this issue [1]-[5]. GTAW is a good process for joining 70/30 Cu-Ni alloy plates but it suffers with low mechanical properties.

Pulsed current gas tungsten arc welding (PC GTAW), is a variation of GTAW process that involves cycling the welding current at a selected regular frequency. The maximum current is selected to give adequate penetration and bead contour, while the minimum is set at a level sufficient to maintain a stable arc [6], [7]. This permit arc energy is used efficiently to fuse a spot of controlled dimensions in a short time producing the weld as a series of overlapping nuggets. By contrast, in constant current welding, the heat required to melt the base material is supplied only during the peak current pulses allowing the heat to dissipate into the base material leading to a narrower heat affected zone (HAZ) [8]. Advantages include improved bead contours, greater tolerance to heat sink variations, lower heat input requirements, reduced residual stresses and distortion, refinement of fusion zone microstructure, and reduced width of HAZ. There are four independent parameters that influence the process are peak current, base current, pulse frequency, and welding speed [7], [8].

Earlier Pulse current was used to weld aluminum and magnesium alloy only. But recent study revealed that, PC GTAW can be used for welding of 70/30 Cu-Ni alloy to greater effect. Grain refinement in 70/30 Cu-Ni alloy was stronger in PC GTAW than CC GTAW However; no thorough study has been reported so far on PC GTAW of 70/30 Cu-Ni alloys and hence the present investigation was carried out.

The effect of some important parameters such as pulse frequency, peak current, base current and welding speed on weld properties is major topics for researchers [9], [10]. In order to study the effect of PC GTAW process parameters, most workers follow the traditional experimental techniques, i.e. varying one parameter at a time while keeping others constant. This conventional parametric design of experiment approach is time consuming and calls for enormous resources. Taguchi statistical design is a powerful tool to identify significant factor from many by conducting relatively less number of experiments. However, this design fundamentally does not account for the interaction among processing parameters. In view of cost and time saving, occasionally these interactions can be neglected. If mandatory, the missing interactions can be analyzed by further running the required experiments.

Though research work applying Taguchi methods on casting methods and fusion welding processes have been reported in literature [9]-[14], it appears that the optimization of PC GTAW process parameters of 70/30 Cu-Ni alloy using Taguchi method has not been reported yet. Considering the above facts, the Taguchi L16 method is adopted to analyze the effect of each processing parameters (i.e. pulse frequency (PF), peak current (PC), base current (BC), and welding speed (WS) for optimum tensile strength of PC GTAW of 70/30 Cu-Ni alloy welds.

II. Taguchi Method

Taguchi method is an efficient problem solving tool, which can upgrade/improve the performance of the product, process, design and system with a significant slash in experimental time and cost [15]. This method that combines the

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experimental design theory and quality loss function concept has been applied for carrying out robust design of processes and products and solving several complex problems in manufacturing industries. Further, this technique determines the most influential parameters in the overall performance. The optimum process parameters obtained from the Taguchi method are insensitive to the variation in environmental condition and other noise factors [16]. The number of experiments increases with the increase of process parameters. To solve this complexity, the Taguchi method uses a special design of orthogonal array to study the entire process parameter space with a small number of experiments only. Taguchi defines three categories of quality characteristics in the analysis of (Signal/Noise) ratio, i.e. the lower-the-better, the larger-the-better and the nominal -the-better. The S/N ratio for each of process parameter is computed based on S/N analysis. Regardless of the category of the quality characteristics, a larger S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of process parameter is the level of highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) can be performed to see which process parameter is statistically significant for each quality characteristics.

III. Pulsed Current TIG Welding Process Parameters

An Ishikawa diagram (cause and effect diagram)[17] was constructed as shown in Fig. 1 to identify the Pulsed current TIG process parameters that may influence the quality of Pulsed TIG joints. From Fig. 1, Pulsed TIG welding process parameters such as pulse frequency, peak current, base current and welding speed play a major role in deciding the weld quality. In the present investigation, four level process parameters i.e. pulse frequency (PF), peak current (PC), base current (BC) and welding speed (WS) were considered. Trail experiments were carried out using 5 mm thick rolled plates of 70/30 Cu-Ni alloy to fix the working range of Pulsed TIG welding process parameters. The chemical composition and mechanical properties of the base metal 70/30 Cu-Ni alloy and filler wire (70/30 ER CuNi) used in this investigation are given in Tables I-III respectively.

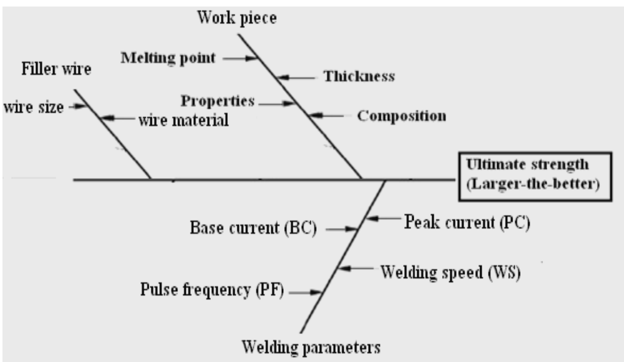

Fig. 1 Cause and effect diagram

A. Important Parameters

From [7]-[10], the predominant factors of pulse frequency, peak current, welding speed and base current which have great influence on the tensile strength of pulsed current GTA welded joints were identified.

B. Working Limits of Parameters

The composition and mechanical properties of the base metal are listed in Tables I and II, respectively. A large number of trial runs were carried out using 5mm thick rolled plates of 70/30 Cu-Ni alloy to find out feasible working limits of pulsed current GTAW parameters. Different combinations of pulsed current parameters were used to carry out the trial runs. The bead contour, bead appearance and weld quality were inspected to identify the working limits of the welding parameters, leading to the following observations. 1) If the peak current was less than 200 A, there were incomplete penetration and lack of fusion. For peak current greater than 230 A, undercut and spatter were observed on the weld bead surface. 2) If the base current was lower than 95 A, the arc length was found to be short. For base current greater than 125 A, the arc becomes unstable and the arc wandering was observed due to increased arc length. 3) If the pulse frequency was lower than 0.5 Hz, the bead appearance and contours were comparable to those of constant current weld beads. When the frequency was greater than 5 Hz, more arc glare and arc spatter were observed. 4) If the welding speed decreases beyond 140mm/min, the penetration also will decrease due to the pressure of the large amount of weld pool beneath the electrode, which will cushion the arc penetrating force were observed [18]. If welding speed was increasing beyond 170 mm/min, width of weld bead reduced, decreasing penetration of the weld and the weld bead formation was not smooth [19].

TABLE I
Chemical Composition of 70/30 Cu-Ni

Material	Ni	Fe	Mn	Pb	Zn	others	Cu
70/30 Cu-Ni	32.50	0.50	0.10	0.02	0.50	0.1	REST

TABLE II
Mechanical Properties of 70/30 Cu-Ni (Base Material (Bm))

Sl. No.	Material	Ultimate Tensile Strength (N/mm2)	Elongation (%)	Vickers Hardness Number (HN)
1	70/30 Cu-Ni	140	412.3	120

Hence, the range of process parameters such as pulse frequency was selected as 0.5 – 5.0 Hz, Peak current was selected as 200 – 230 A, Base current was selected as 95 – 125 A and welding speed was selected as 140 -170 mm/min, The PC GTAW process parameters along with their ranges are given in Table IV.

TABLE III
CHEMICAL COMPOSITION OF FILLER WIRE ERCUNI (70/30 CU-NI)

Material	Ni	Fe	Mn	Pb	P	Si	Ti	others	Cu
Filler ERCuNi (70/30 Cu-Ni)	29.31	0.40	0.65	0.015	0.001	0.058	0.28	0.1	REST

TABLE IV
PROCESS PARAMETERS WITH THEIR RANGE AND VALUES AT FOUR LEVELS

Level	Peak current (A)	Base current (A)	Pulse frequency (Hz)	Welding speed (%)
Range	200 – 230 A	95 – 125 A	0.5 -5.0 Hz	140-150 mm/min
Level 1	200	95	0.5	140
Level 2	210	105	1.0	150
Level 3	220	115	3.0	160
Level 4	230	125	5.0	170

TABLE V
MAIN EFFECTS OF TENSILE STRENGTH (MEANS AND S/N RATIO)

Sl. No.	Input parameter				Response				
	Peak current (A)	Base current (A)	Pulse frequency(Hz)	WS (mm/ min)	T1	T2	T3	Mean	S/N ratio
1	200	95	0.5	140	325.0	318	330	324.3	50.21
2	200	105	1	150	340.0	349.5	345.5	345.0	50.75
3	200	115	3	160	360.0	350	340	350.0	50.88
4	200	125	5	170	299.0	298	288	295.0	49.39
5	210	95	1	160	335.0	340	345	340.0	50.62
6	210	105	0.5	170	336.0	339	345	340.0	50.62
7	210	115	5	140	330.0	334	320	328.0	50.31
8	210	125	3	150	355.0	360	341	352.0	50.93
9	220	95	3	170	330.0	330	339	330.0	50.37
10	220	105	5	160	332.0	314	320	322.0	50.15
11	220	115	0.5	150	345.0	340	329	338.0	50.57
12	220	125	1	140	330.0	342	327	330.0	50.37
13	230	95	5	150	320.0	325	315	320.0	50.10
14	230	105	3	140	340.0	350	330	340.0	50.62
15	230	115	1	170	318.0	315	327	319.0	50.07
16	230	125	0.5	160	309.0	308.7	300	305.9	49.71

IV. SELECTION OF ORTHOGONAL ARRAY (OA)

Before selecting a particular OA to be used as a matrix for conducting the experiments, the following two points must be considered: 1) The number of parameters and interactions of interest; 2) The number of levels for the parameters of interest. The non-linear behavior, if exists among the process parameters, can only be studied if more than two levels of the parameters are used. Therefore, each parameter was analyzed at four levels. To limit the study, it was decided not to study the second order interaction among the parameters. Each four level parameter has 3 degrees of freedom (DOF=number of levels−1), the total DOF required for 4 parameters each at four levels is 12 (=4× (4−1)). As per Taguchi's method, the total DOF of selected OA must be greater than or equal to the total DOF required for the experiment. So an L16 OA having 15(=16−1) degrees of freedom were selected for the present analysis.

V. EXPERIMENTAL DETAILS

The investigations were carried out on 70/30 Cu-Ni (5 mm thick) rolled plate. The rolled plates of 70/30 Cu-Ni alloy of 5 mm in thickness were cut into the required size (100 mm× 55 mm) by power hacksaw cutting and milling. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the joints by M/s Miller syncrowave 350 LX, CC-AC/DC square wave power source TIG welding machine. The welded joints were sliced shown in Fig. 2 (a)) using a power hacksaw and then machined to the required dimensions as shown in Fig. 2 (b). The American Society for Testing of Materials (ASTM E8) guidelines was followed for preparing the test specimens. The smooth tensile specimens were prepared to evaluate ultimate tensile strength. At each experimental level three specimens were prepared to minimize the noise factor. Tensile test was carried out in 100 KN, computer controlled Universal Testing Machine.

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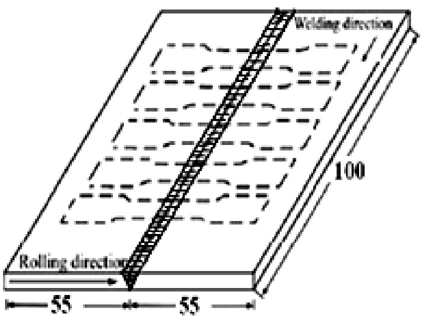
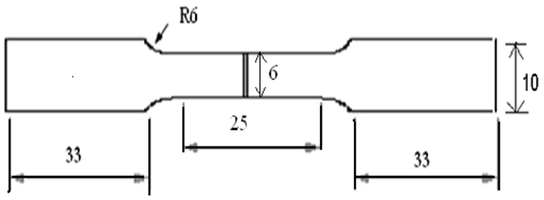


(a)



(b)

Fig. 2 (a) Scheme of welding with respect to rolling direction and extraction of tensile specimens, (b) ASTM- E8 dimensions of flat smooth tensile specimen

VI. RESULTS AND DISCUSSION

A. Signal to Noise Ratio

Tensile strength is the main characteristic considered in this investigation describing the quality of Pulsed current TIG welded joints. In order to assess the influence of factors on the response; the means and Signal-to-Noise ratios (S/N) for each control factor can be calculated. The signals are indicators of the effect on average responses and the noises are measures of the influence on the deviations from the sensitiveness of the experiment output to the noise factors. The appropriate S/N ratio must be chosen using previous knowledge, expertise, and understanding of the process. When the target is fixed and there is trivial or absent signal factor (static design), it is possible to choose the signal-to-noise (S/N) ratio depending on the goal of the design [20]. In this study, the S/N ratio was chosen according to the criterion of the larger-the-better, in order to maximize the response. In the Taguchi method, the signal to noise ratio is used to determine the deviation of the quality characteristics from the desired value. The S/N ratio ηj (larger-the-better) in the jth experiment can be expressed as

$$\eta j = - 10*\text{Log}10\ (\text{sum}\ (1/Yijk**2)/n) \quad (1)$$

where n is the number of tests and Yijk is the experimental value of the ith quality characteristics in the jth experiment at the kth test.

In the present study, the tensile strength data were analyzed to determine the effect of pulsed current TIG welding process parameters. The experimental results were then transformed into means and signal-to-noise (S/N) ratio. In this work, 16 means and 16 S/N ratios were calculated and the estimated tensile strength, means and signal-to-noise (S/N) ratio are given in Table V. The analysis of mean for each of the experiments will give the better combination of parameters levels that ensures a high level of tensile strength according to the experimental set of data. The mean response refers to the average value of performance characteristics for each parameter at different levels. The mean for one level was calculated as the average of all responses that were obtained with that level. The mean response of raw data and S/N ratio of tensile strength for each parameter at level 1, 2, 3 and 4 were calculated and are given in Table VI.

TABLE VI
MAIN EFFECTS OF TENSILE STRENGTH (MEANS AND S/N RATIO)

Process parameter	Level	Means				S/N ratio			
		PC	BC	PF	WS	PC	BC	PF	WS
Average value	L1	328.6	328.6	327.0	330.6	50.31	50.33	50.28	50.38
	L2	340.0	336.8	333.5	338.8	50.63	50.54	50.46	50.59
	L3	330.0	333.8	343.0	329.5	50.37	50.46	50.70	50.34
	L4	321.2	320.7	316.3	321.0	50.13	50.10	49.99	50.12
Delta		18.8	16.0	26.8	17.8	0.50	0.44	0.71	0.47
RANK		2	4	1	3	2	4	1	3

TABLE VII
ANOVA (ANALYSIS OF VARIANCE) FOR TENSILE STRENGTH (MEAN)

Source	DF	Seq SS	MS	F	% of contribution
PC	3	716.6	238.85	4.94	19.90
BC	3	591.2	197.06	4.08	16.41
PF	3	1516.3	505.44	10.46	42.10
PT	3	632.6	210.87	4.36	17.56
Residual Error	3	145	48.33		4.03
Total	15	3601.7			100.00

TABLE VIII
ANOVA (ANALYSIS OF VARIANCE) FOR TENSILE STRENGTH (S/N RATIO)

Source	DF	Seq SS	MS	F	% of contribution
PC	3	0.5059	0.16864	4.78	19.61
BC	3	0.4464	0.14879	4.22	17.30
PF	3	1.0693	0.35643	10.11	41.44
PT	3	0.4530	0.15099	4.28	17.56
Residual Error	3	0.106	0.03526		4.10
Total	15	2.5803			100.00

DF─ Degrees of freedom, Seq SS─ Sequencial sum of squares, Adj SS─Adjusted sum of square, Adj MS─Adjusted mean square, F─Fisher ratio, P─probability that exceeds the 95 % confidence

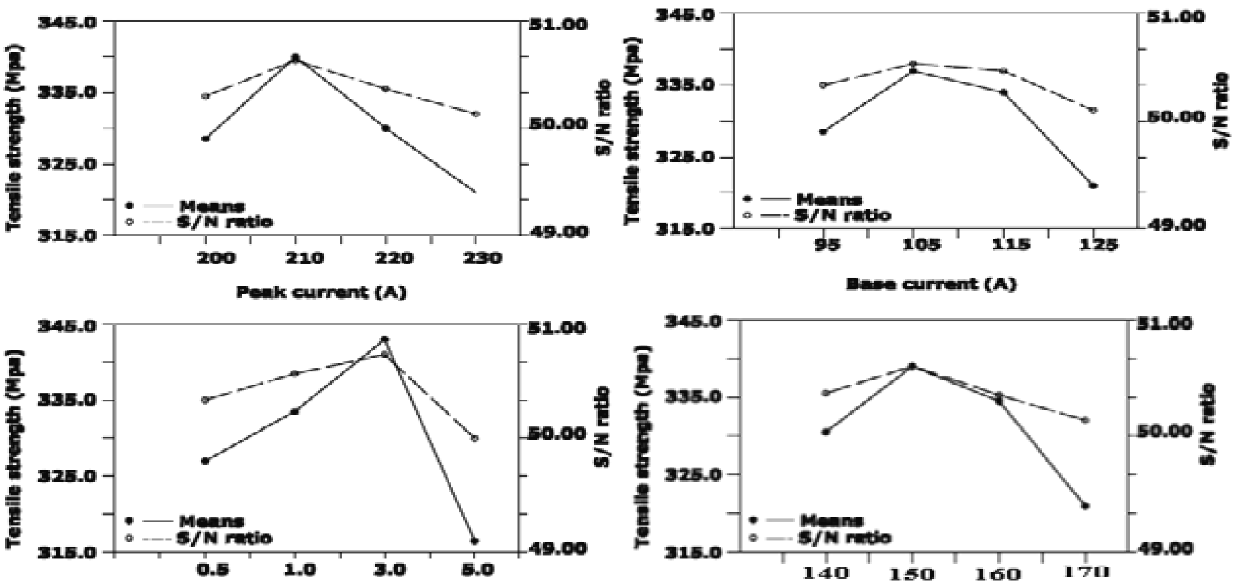


Fig. 3 Comparison of mean effect and S/N ratio of tensile strength

The means and S/N ratio of the various process parameters when they changed from the lower to higher levels are also given in Table VI. It is clear that a larger S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of process parameter is the level of highest S/N ratio [21]. The mean effect and S/N ratio (Fig. 3) for tensile strength were calculated by statistical software [22], indicating that the tensile strength was at maximum when pulse frequency at level 3, peak current at level 2, base current at level 2 and welding speed at level 2, i.e. pulse frequency at 3.0 Hz, peak current at 210 A, base current at 105 A and welding speed at 150 mm/min. The comparison of mean effect and S/N ratio are presented in Fig. 3.

B. Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) test was performed to identify the process parameters that are statistically significant. The purpose of the ANOVA test is to investigate the significance of the process parameters which affect the tensile strength of Pulsed current TIG welding joints. The ANOVA results for tensile strength of means and S/N ratio are given in Tables VII and VIII respectively. In addition, the F-test named after Fisher can also be used to determine which process has a significant effect on tensile strength. Usually, the change of the process parameter has a significant effect on the quality characteristics, when F is large. The results of ANOVA indicate that the considered process parameters are highly significant factors affecting the tensile strength of Pulsed current TIG welding joints in the order of pulse frequency, peak current, welding speed and base current.

C. Interpretation of Experimental Results

1. Percentage of Contribution

The percentage of contribution is the portion of the total variation observed in the experiment attributed to each significant factors and/or interaction which is reflected. The percentage of contribution is a function of the sequential of squares for each significant item; it indicates the relative power of a factor to reduce the variation. If the factor levels are controlled precisely, then the total variation could be reduced by the amount indicated by the percentage of contribution. The percentage of contribution of the pulse frequency, peak current, welding speed and base current are shown in Fig. 4.

2. Estimation of Optimum Performance Characteristics

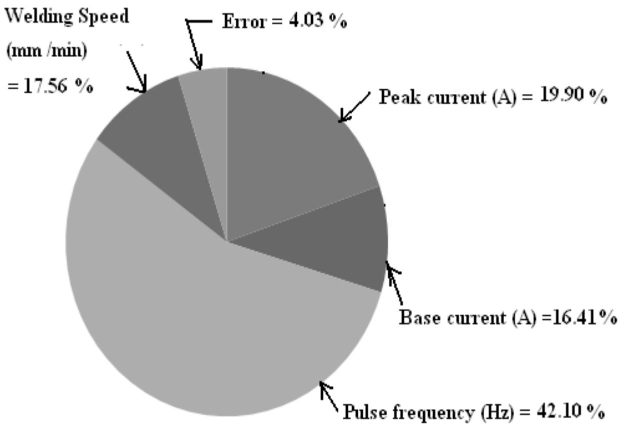


Fig. 4 Percentage of contribution of factors (Means)

The methods described in this paper for tensile strength prediction and optimization can eliminate the need for performing experiments on the basis of the conventional trial and error method which is time consuming and economically not justifiable. The present study is aimed at to identify the most influencing significant parameter and percentage contribution of each parameter on tensile strength of PC GTAW of 70/30 Cu-Ni alloys joints by conducting minimum number of experiments using Taguchi orthogonal array. Based on the highest values of the S/N ratio and mean levels (Fig. 3) for the significant factors PC, BC, PF and WS the overall optimum condition thus obtained were PC L2, BC L2, PF L3 and WS L2. No reports were available on optimization of pulsed TIG welding process parameters on Cupronickel (Cu-Ni) alloys by using Taguchi analysis.

Once an experiment is conducted and the optimum treatment condition within the experiment is determined, one of two possibilities exists:

1) The prescribed combination of factors level is identical to one of those in the experiment;
2) The prescribed combination of factors level is not included in the experiment.

It must be noted that the above combination of factor levels PC L2, BC L2, PF L3 and WS L2 are not among the nine combinations tested for the experiment. This is expected because of the multifactor nature of the experimental design employed (16 from 4^4 =256 possible combinations).The optimum value of tensile strength is predicted at the selected levels of significant levels of significant parameters. The estimated mean of the response characteristics (tensile strength) can be computed as

$$\text{Tensile strength (TS)} = \text{PC L2} + \text{BC L2} + \text{PF L3} + \text{PT L2} - 3\text{xT} \quad (2)$$

where T is the overall mean of tensile strength, MPa (Table V); PF L3 is the average tensile strength at third level of pulse frequency, 3.0 Hz; PC L2 is the average tensile strength at second level of peak current, 210 A, BC L2 is the average tensile strength at second level of base current, 105 A and WS L2 is the average tensile strength at second level of welding speed 150 mm/min. Substituting the values of various terms in (2), then

$$\text{Tensile strength} = 340.0 + 336.8 + 343.0 + 338.8 - 3 \text{x} 330.0 = 368.8 \text{ MPa}$$

D. Confirmation Test

For confirmation, experiments were conducting at the optimum setting of process parameters namely pulse frequency at level 3 (3 Hz), peak current at level 2 (210 A), base current at level 2(105 A) and welding speed at level 2 (150 mm/min) and the experimental average value of the three tensile test samples readings of PC GTAW of 70/30 Cu-Ni alloy welds was found ((363.8+362.2+363)/3=) 363.0MPa. By Taguchi method, the predicted optimal tensile strength value at 95% confidence level was 368.8MPa.

VII. Conclusions

1) The percentage of contribution of PC GTAW process parameters was evaluated. It is found that the pulse frequency (Hz) has 42.10 % contribution, peak current (A) has 19.90 % contribution; welding speed (mm/min) has 17.56 % and base current (A) has 16.41% contribution to tensile strength of welded joints.
2) The optimum value of process parameters such as pulse frequency , peak current, base current and welding speed are found to be 3.0 Hz, 210 A, 105 A and 150 mm/min respectively.

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