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Optimization of the Process Parameters in Resistance Spot Welding of IS410:2006 Grade CuZn40 Brass Material Using Taguchi Method

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Abstract: ***Resistance spot welding process is widely used in industry for sheet joining purposes such as Automobile, Aerospace Industry. The problems associated with resistance spot welding are tendency of alloying with the electrode resulting in increased wear of copper electrodes and subsequent deterioration of weld quality. More current and time lead to expulsion and overheating of the electrode affects the quality of the weld and less value result in insufficient weld strength. The complex behaviour of this process must be analysed to set the optimum parameters to obtain robustness in the weld quality. The experimentation carried under varying welding current, welding time, electrode force and hold time. Taguchi Design concept of L_9 orthogonal array has been used to determine analysis of variance for determining most significant parameters affecting the spot weld performance. The experimental results confirmed the validity of used Taguchi Method for enhancing welding performance and optimizing the welding parameters in resistance spot welding process.***

Keywords: Resistance spot welding, Taguchi method, Optimization, analysis of variance, weld performance.

1. Introduction

In Resistance spot Welding process, coalescence of metal is produced at faying surface by the heat generated at the joint by the contact resistance to the flow of electric current. Heat obtained at the end of the welding also raises the temperature of both electrodes and workpieces, consequently, micro-structural change might be seen around the welding zone due to the distributed heat. The heat affected zone (HAZ) should be as small as possible in a well qualified weld. The electrode cap life is reduced due to excessive heat and deteriorates the weld quality. Therefore, the electrodes are cooled via water circulation through channels opened inside them. The qualities of the spot welded joints are defined by the mechanical properties and size of the heat affected zone. The weld strength is measured by a number of standardized destructive tests, which subject the weld to different types of loading. Some of these are tension-shear, impact, torsion, fatigue and hardness.

The quality of the weld is influenced by the welding parameters such as weld current, electrode pressure, weld time and hold time. [1]

Various optimization methods can be applied to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables. The main objective of Taguchi Method is to investigate optimum parameters for obtaining the higher tensile strength. The Indentation created on the sheet surfaces by electrodes under electrode force during welding is having the significant effect on weld quality. Too much indentation may also create a weak link between a weld and its parent metal sheets because of the reduced thickness in the sheet near the wall of indentation. By correctly choosing welding parameters and welder set up, indentation and strength. Indentation must be less than 20% of workpiece thickness. [2]

Brasses have good electrical and thermal conductivities and are markedly superior in this respect to ferrous alloys, nickel based alloys and titanium. Their relatively high conductivity, combined with corrosion resistance makes them an ideal choice for the manufacture of electrical equipments. Condenser and heat exchanger tubing also require the good thermal conductivity of brass. Brasses have excellent resistance to corrosion therefore; it is used for sea water lines, steam condensers and desalination equipment. Brasses are essentially non-magnetic and are used for electronic equipments.[3]

Mostly, the quality characteristic of the product is related to the various product parameters and noise factors through a complicated, non linear function. It is possible to find many combinations of product parameter values which contributes to the product's quality characteristic under nominal noise conditions. Nonlinearity causes the different product parameter combinations can exhibit quite different variations in the quality characteristic, even though the noise factor variations are the same. The fundamental aim of Robust Design is to exploit the non linearity to find a combination of product parameter values that gives the smallest variation in the value of the quality characteristic around the desired target value. [6]

2. Experimental Planning Method

The Taguchi design method is a simple and robust technique for optimizing the process parameters. In this method, the main influential parameters on the product characteristics are arranged at different rows in a designed orthogonal array(OA). By this arrangement, completely randomized experiments can be conducted. The benefit of the Taguchi Method is that it emphasizes a mean performance characteristics value close to the target value instead of a value within certain specification limits, thus improving the product quality. [4]

Steps of Taguchi Method are as follows:-

A] Planning Phase
1. State the problem or area of concern.
2. State the objectives of the experiment.
3. Select the quality characteristics and measurement systems.
4. Select the factors that may influence the selected quality characteristics.
5. Identify control and noise factors.
6. Select levels for the factors.
7. Select the appropriate orthogonal array (OA).
8. Select interactions that may influence the selected quality characteristic.
9. Assign factors to orthogonal arrays.

B] Conducting Phase
10. Conducting tests described by trials in OAS.

C] Analysis Phase
11. Analyze and interpret results of the experimental trials.
12. Conduct confirmation experiment. [7]

Designing a product or a manufacturing process is a complex activity. The output of the activity is a set of drawings and written specifications that specify how to make the particular product. Three essential elements of these drawings and specifications are:
a) System architecture,
b) Nominal values for all parameters of the system
c) The tolerance or the allowable variation in each parameter.

Optimizing a product design means determining the best architecture, the best parameter values and the best tolerances. A number of parameters can influence the quality characteristic or response of the product. The classifications of the parameters are:
a) Signal Factors: These are the parameters set by the user to express the intended value for the response of the product. The signal factors are selected by the design engineer based on the engineering knowledge of the product being developed.
b) Noise factors: Certain parameters cannot be controlled by the designer and are called noise factors. The levels of the noise factors change from one unit to another, from one environment to another, and from time to time. the noise factors cause the response to deviate from the target specified by the signal factor and lead to quality loss.
c) Control factors: These are parameters that can be specified by the designer. Each control factor can take multiple values, called levels.

Robust Design projects can be classified on the basis of the nature of the signal factor and the quality characteristic. In some problems, the signal factor takes constant value; such problems are called static problems. The variation in the signal factor gives rise to the case of dynamic problem. [6]

Joshi K.N, Patil.B. T, Satao S. and Chandrababu D (2014) used L_{27} orthogonal array for "Optimization Of Variation In Wall Thickness Of Deep Drawn Cup Using Virtual Design Of Experiments". Their research work suggest use of DOE methodology for optimization. [8]

3. Experimental Details

The workpiece selected is IS410:2006 Grade CuZn40 Brass material with Length 152mm, width 40mm and Thickness 1mm.

Table 1: Chemical Analysis and Mechanical Properties of Workpiece Materials

Percent Composition (%)	Cu	Zn	Pb	Fe
	60.34	39.56	0.01	0.093
Mechanical Properties	Yield Strength (N/mm^2)	Tensile strength (N/mm^2)	% Elongation	Hardness in HV
	303.56	418.97	45.36	111.67

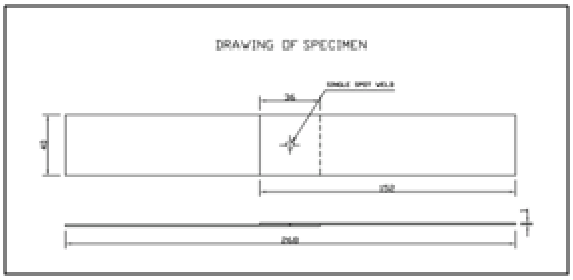


Figure 1: Shape and loading condition of the test samples

Table 2: Process Parameter and their Levels

Symbol	Process Parameter	Level 1	Level 2	Level 3
X_1	Weld Current in Amp	150	160	170
X_2	Weld Time in sec	0.12	0.14	0.16
X_3	Hold Time in sec	0.08	0.1	0.12
X_4	Electrode Pressure in bar	1.8	2	2.2

No. of. Experiments = (No. of. Levels)$^{\text{No. of. Factors}}$
$= (3)^4$
$= 81$

Considering Fractional Experiment, For Four Factors and three levels L_9 orthogonal array is selected.

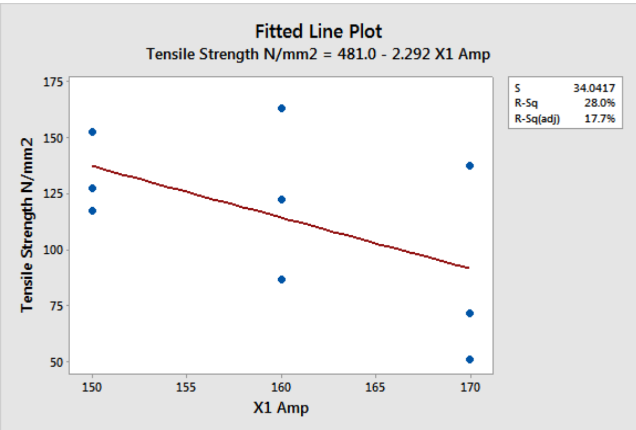
Table 3: Experimental Layout using an L_9 Orthogonal Array

Exp. No.	Process Parameter Level			
	Weld Current X_1	Weld Time X_2	Hold Time X_3	Electrode Pressure X_4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

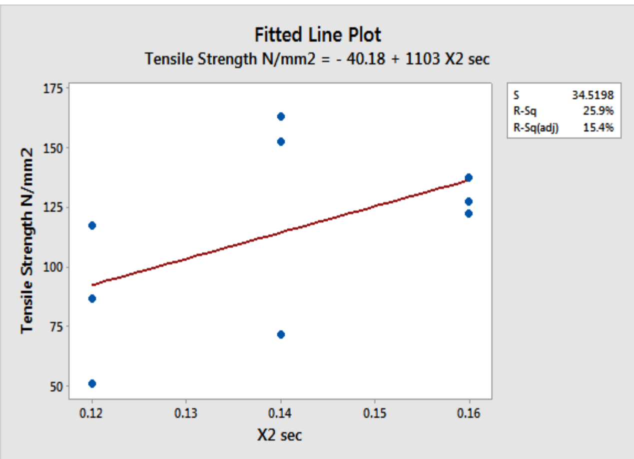
Table 4: Experimental Results for the Tensile shear strength and Hardness

Exp. No.	X_1 Amp	X_2 sec	X_3 sec	X_4 bar	Tensile Strength N/mm2	Hardness Vickers HV
1	150	0.12	0.08	1.8	117.14	91.03
2	150	0.14	0.1	2	152.79	89.43
3	150	0.16	0.12	2.2	127.33	99.03
4	160	0.12	0.1	2.2	86.58	95.5
5	160	0.14	0.12	1.8	162.98	92.5
6	160	0.16	0.08	2	122.23	101.67
7	170	0.12	0.12	2	50.93	93.43
8	170	0.14	0.08	2.2	71.3	94
9	170	0.16	0.1	1.8	137.51	95.06

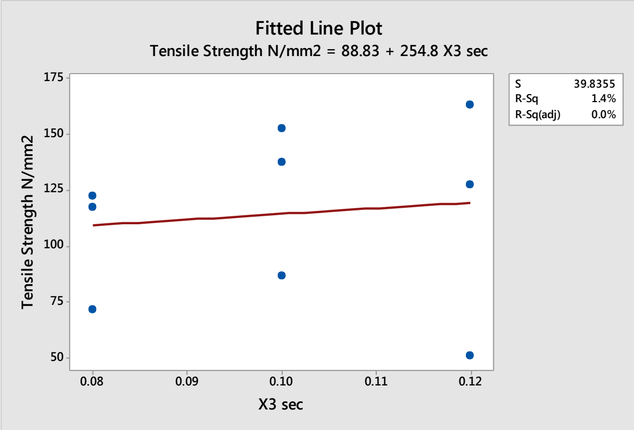
4. Main Effects Plot



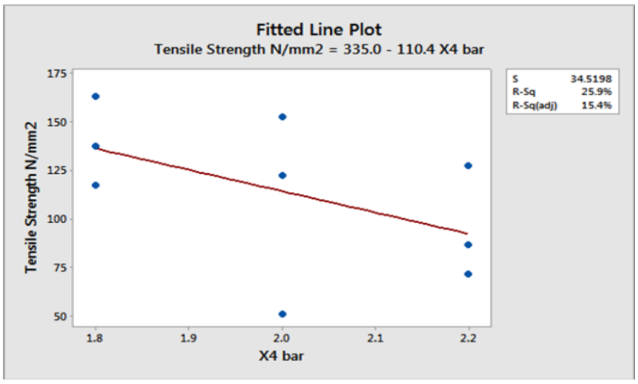
Graph No. 1: Weld Current X_1 vs Tensile Strength



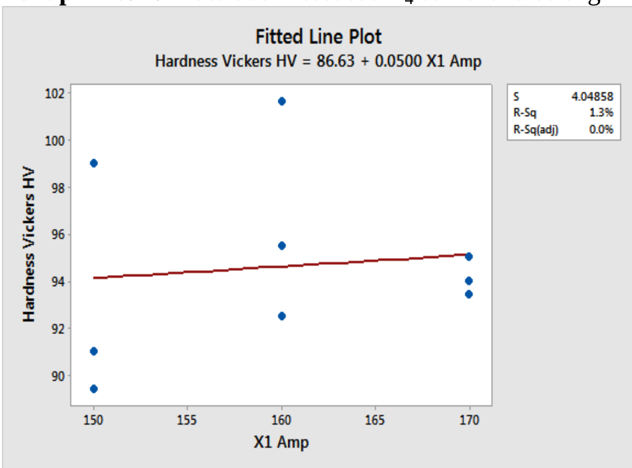
Graph No. 2: Weld Time X_2 vs Tensile Strength



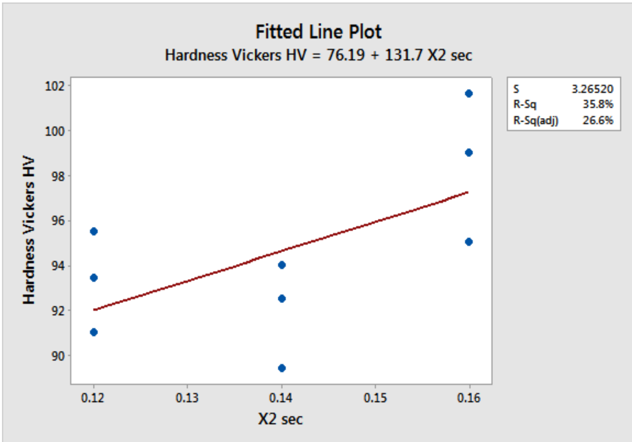
Graph No. 3: HOLD TimeX_3 vs Tensile Strength



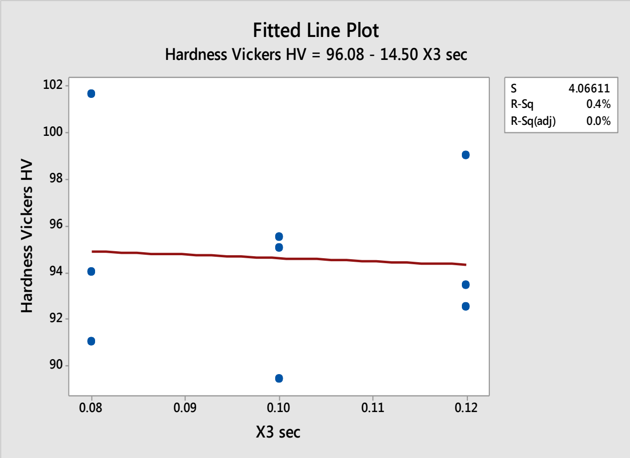
Graph No. 4: Electrode Pressuese X_4 vs Tensile Strength



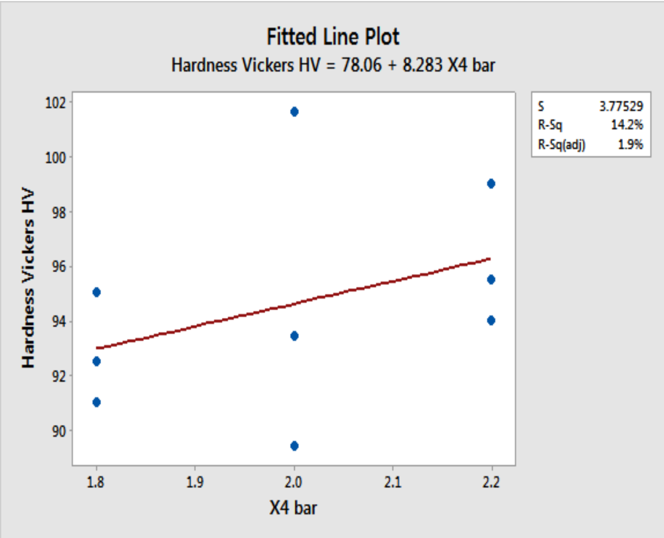
Graph No. 5: Graph No. 1 Weld Current X_1 vs Hardness Vicker



Graph No. 6: Weld Time X_2 vs Hardness Vicker



Graph No. 7: HOLD TimeX_3 vs Hardness Vicker



Graph No. 8: Electrode Pressuese X_4 vs Hardness Vicker

Table 5: ANNOVA for the Response Tensile Strength

Exp. No.	X_1	X_2	X_3	X_4	Responses Y_1	Responses Y_1^2
1	1	1	1	1	117.14	13721.78
2	1	2	2	2	152.79	23344.78
3	1	3	3	3	123.33	16212.93
4	2	1	2	3	86.58	7496.096
5	2	2	3	1	162.98	26562.48
6	2	3	1	2	122.23	14940.17
7	3	1	3	2	50.93	2593.865
8	3	2	1	3	71.3	5083.69
9	3	3	2	1	137.51	18909
					1028.79 ΣY_1	**128864.8 ΣY_1^2**

	Sum of Square SS	DOF	Mean sum of square MSS	% contribution
Total	11263.8124	8		
X_1	3568.4082	2	1784.204	31.68029
X_2	3896.6792	2	1948.34	34.59467
X_3	732.0554	2	366.0277	6.49918
X_4	3066.6696	2	1533.335	27.22586
Error	0	0		

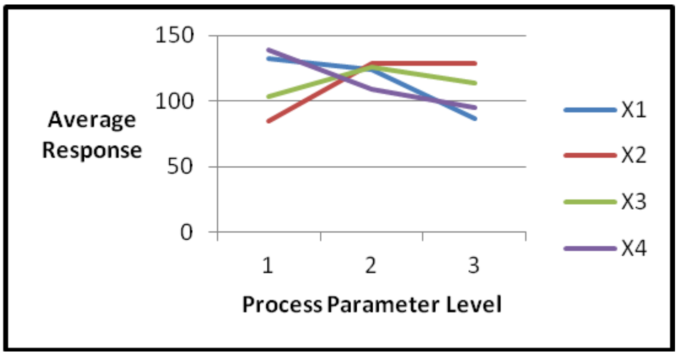
Table 6: ANNOVA for the Response Hardness

Exp. No.	X_1	X_2	X_3	X_4	Responses Y_2	Responses Y_2^2
1	1	1	1	1	91.03	8286.461
2	1	2	2	2	89.43	7997.725
3	1	3	3	3	99.03	9806.941
4	2	1	2	3	95.5	9120.25
5	2	2	3	1	92.5	8556.25
6	2	3	1	2	101.67	10336.79
7	3	1	3	2	93.43	8729.165
8	3	2	1	3	94	8836
9	3	3	2	1	95.06	9036.404
					851.65 ΣY_2	80705.98 ΣY_2^2

	Sum of Square SS	**DOF**	**Mean sum of square MSS**	**% contribution**
Total	116.2371556	8		
X_1	18.24275556	2	9.121378	15.69443
X_2	73.23442222	2	36.61721	63.00431
X_3	8.083622222	2	4.041811	3.477211
X_4	16.67635556	2	8.338178	14.34684
Error		0		

Factors	**Sum of responses**			**Average response**		
	1	2	3	1	2	3
X_1	397.26	371.79	259.74	132.42	123.93	86.58
X_2	254.65	387.07	387.07	84.88333	129.0233	129.0233
X_3	310.67	376.88	341.24	103.5567	125.62.67	113.7467
X_4	417.63	325.95	285.21	139.21	108.65	95.07

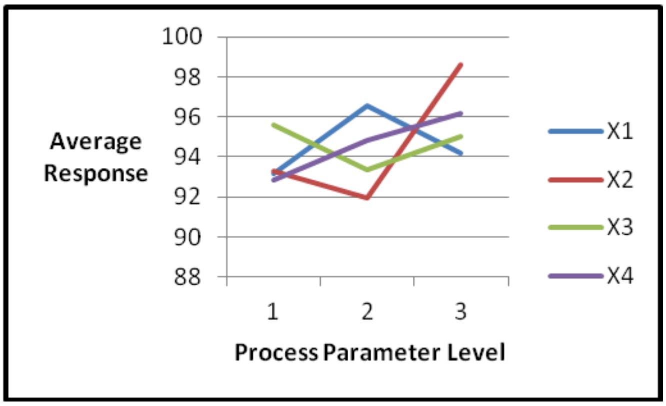
CF = 117600.9849



Graph No. 9: Average Response (Y_1) vs Process Paraameter Level

Factors	**Sum of responses**			**Average response**		
	1	2	3	1	2	3
X_1	279.49	289.67	282.49	93.16333	96.55667	94.16333
X_2	279.96	275.93	295.76	93.32	91.97667	98.58667
X_3	286.7	279.99	284.96	95.56667	93.33	94.98667
X_4	278.59	288.53	288.53	92.86333	94.84333	96.17667

CF = 80589.74694



Graph No. 10: Average Response (Y_2) vs Process Paraameter Level

5. Regression Statistics and Analysis of Variance

A. For Tensile Strength (Y_1)

Regression Statistics	
Multiple R	0.90143134
R Square	0.812578461
Adjusted R Square	0.625156923
Standard Error	22.97325102
Observations	9

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	9152.73135	2288.183	4.33556606	0.092213449
Residual	4	2111.08105	527.7703		
Total	8	11263.8124			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	521.765	194.6334417	2.680757	0.05518515
X1 Amp	-2.292	0.937879046	-2.44381	0.07091641
X2 sec	1103.5	468.9395228	2.353182	0.07824297
X3 sec	254.75	468.9395228	0.543247	0.61581656
X4 bar	-110.35	46.89395228	-2.35318	0.07824297

B. For Hardness in Vickers (Y_2)

Regression Statistics	
Multiple R	0.71893094
R Square	0.5168617
Adjusted R Square	0.03372339
Standard Error	3.74695284
Observations	9

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	60.07853333	15.01963	1.069801	0.474717
Residual	4	56.15862222	14.03966		
Total	8	116.2371556			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	53.0777778	31.74484646	1.672012	0.169839
X1 Amp	0.05	0.152968709	0.326864	0.76016
X2 sec	131.666667	76.48435449	1.721485	0.160271
X3 sec	-14.5	76.48435449	-0.18958	0.858869
X4 bar	8.28333333	7.648435449	1.08301	0.339724

6. Mathamatical Formulation

Tensile Strength Y_1

$$= 521.765 - 2.292X_1 + 1103.5\, X_2 + 254.75X_3 - 110.35X_4$$

Hardness Y_2

$$= 53.07778 + 0.05X_1 + 131.6667X_2 - 14.5X_3 + 8.283333X_4$$

Where,

$50 \leq$ Tensile Strength ≤ 170

$85 \leq$ Hardness in Vickers ≤ 105

$150 \leq X_1 \leq 170$

$0.12 \leq X_2 \leq 0.16$

$0.08 \leq X_3 \leq 0.12$

$1.8 \leq X_4 \leq 2.2$

7. Conclusions

The Taguchi Method has been applied for simultaneous consideration of multiple responses such as Tensile strength and the hardness to optimize the resistance spot welding parameters, such as weld current, weld time, hold time, and electrode pressure.

Based on the modelling and optimization results it can be concluded that.

1) Considering Higher the better criteria for the response Y_1, Tensile shear strength, the Local Optimum values for the RSW process parameters are weld current 160 Amp, weld time 0.14 sec electrode pressure 1.8 bar.
2) Considering Higher the better criteria, for the response Y_2, Hardness, the Local Optimum Values for the RSW process parameters are weld current 160 Amp, weld time 0.16 sec electrode pressure 2 bar.
3) In the present case study, the degree of freedom for the error is zero. Hence an approximate estimate of the error sum of squares is obtained by pooling the sum corresponding to the factors having the lowest mean square. [5]
4) In the present case the factor X_3, hold time is used to estimate the error sum of squares. The factor X_3 contributes to 6.49% for the response Tensile shear strength Y_1 and 3.48% for the response hardness, Y_2.

Response Variable	Actual Value	Estimated Value	% Error
i.Tensile Strength	162.98	141.475	13.194%
ii. Hardness	101.67	97.5	4.1%

5) The Sample Specimens used are IS 410:2006 Grade CuZn 40 Brass material, In Future there is a wide scope for the Resistance spot welding process of Brass Material.

8. Acknowledgements

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