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Distortion Control in laser welding of SS316L using Taguchi optimisation Techniques

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Abstract

Process controlling is critical as customer demands for quality, performance, and cost continue to rise; safety and reliability are critical for continued expansion, ensuring a process that results in the least distortion possible following the laser welding process through the use of Design of Experimentation. The current trials employ a L4 orthogonal array to measure laser power, welding speed, and Argon shielding parameters. These variables were investigated in order to establish the ideal control level combination of output and its related minimum distortion. The critically is identified using No-way ANOVA within the parameters of 99 % and by optimising the critical parameters of 95 % using Analysis of Variance (ANOVA). The uniformity of the welds was determined using X-ray radiography, and they were found to be free of surface and interior flaws. The results indicate that welding speed and weld processes are critical characteristics, however shielding gas is not.

Key words: Laser Beam Welding, Design of Experiments (DOE), ANOVA, Distortion.

1. Introduction

Structural integrity stability, LBW outperforms the arc weld process in terms of no additional spatter, making it an excellent choice. Welding is done using a gas laser. There must be an active medium, an optical resonator, and a pumping mechanism in order for a laser to work. The emission-induced medium may be found in places where laser activity is essential. Lung Kwang Pan [i] used Taguchi experiments to study Nd: YAG laser settings on thin magnesium alloy plates. There are a number of factors that contribute to optimising tensile strength. In CO2 continuous laser welding methods, Anawa [ii] As part of a Taguchi process, dissimilar materials, including stainless steel & carbon steel sheets, were able to enhance the minimum fusion zone scale by applying different welding and defocused processes that combine various power factors.

The simulation was carried out with elastic-plasticity with temperature-dependent characteristics and examined for distortion & stresses of a 1mm thick layer[iii iv v]. Numerous CO_2 & Nd: YAG laser processes, as well as Taguchi methodologies, were detailed by Aavanish [vi] for process optimization. Moratis et colleagues [vii] investigated the effects of residual stress and deformation on aluminium laser-welding laps using a computer simulation. Within the hardening metal, a laser beam bounces over the dead-end capillary, losing the majority of its energy via the two main processes of heat conduction and radiation.
A 3.5kW CO2 laser beam welding technology was utilised by Buddu et al. [viii] to weld an 8mm thick plate in their experiments. The results have improved the weldments' mechanical properties compared with the base material.

Subashini et al. [ix] investigated weldability investigations using a single-pass for a 10mm thick plate of maraging steel utilising a CO2 laser and a MIG (hybrid) welding method. The findings of the tests reveal good outcomes in terms of weld efficiency and microstructural characteristics. For the experiment, a 3.5kW laser with a single pass was employed. Ramesh et al [x] had experimented with stainless steel grade materials to understand the weldability, mechanical and microstructure of the weldments using the laser beam welding process. Akella et al. utilized the Taguchi approach to describe distortions in longitudinal, weld, and transverse directions in TIG welding processes [xi xii xiii]. Taguchi methods [xiv] have been developed by Phillip j Ross [xv] for industrial applications that include optimised process parameters. The Taguchi method [xvi] is an effective mathematical technique for determining optimal process parameters for design response characteristics. The best parameters can be found with the least amount of testing through a careful experimental design using an orthogonal array and a regular or S/N interpretation of the effects using Taguchi techniques.

The welding qualities of stainless steel 316L material were investigated in this study, specifically for distortion investigations in nuclear fusion reactors. The L4 experimental design is carried out utilising the CO2 laser beam welding technology; too the weld distortion was measured. The criticality within the parameters is discovered using No Way ANOVA, and ANOVA approaches were utilised to optimise all parameters, including LP, WS, & argon flow rate.

2. Experimentation

Stabilising the components and reducing noise variability was performed after the fixtures and equipment had been developed, and in preparation for welding was completed. Since the number of parts was minimal in this experiment, no repetitions were possible since it was just a necessary evaluation. As a result, the report does not include an S/N analysis of the signal to noise ratio. To consider the criticality of the selected parameters [xvii] are identified, an L4 orthogonal array of experimentation was selected. Laser power (LP), welding speed (WS), & argon flow rate are three of the control limitations listed, each with two levels. Fig. 1 shows laser beam weld experiments on plates of 5mm thick, 110mm long and 80mm wide, with a thickness of 5mm. Beam diameter and focus angle were set at 2mm and 90o, respectively, to conduct the experiment.

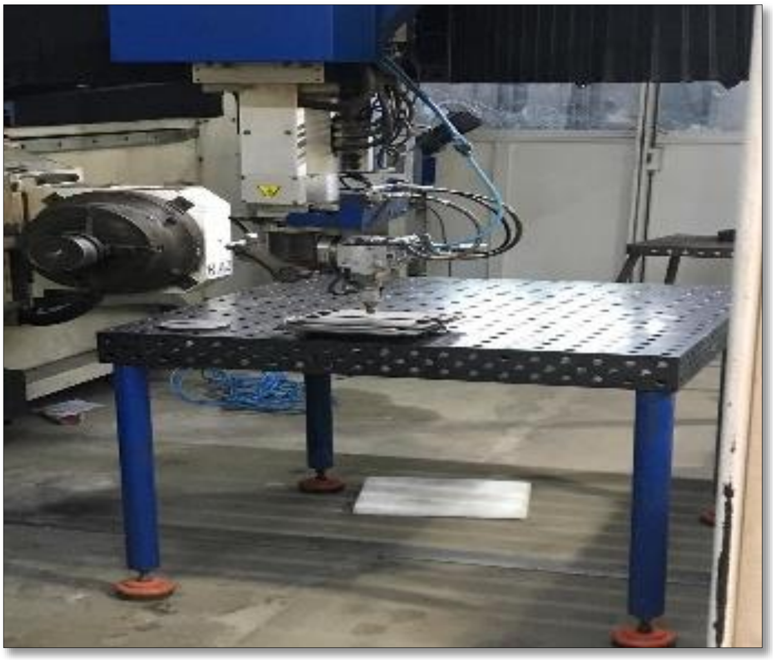


Figure.1 CO_2 Laser Welder

Here, the L4 orthogonal array is employed for two different levels of the experiment parameters mentioned in Table 1. They had considered the cruciality of the controls and set them accordingly. There was no problem with the implementation, and the price was about right. This design allows for Level-1 & Level-2 to be used for each parameter to take account of nonlinear effects. Consider the tests in table 3, seen here orthogonally. 3 parameters of each are available for each variable; two factors of 1 degree of freedom is the minimum requirement. From the X-ray radiography of the weld samples, figure 2 verifies that the welds are defect-free.

Table 1. Process parameters and levels for the experimentation

No.	Welding process parameter with levels		
	LP, kW	**WS, m/min**	**Shield gas flowrate, lit/min**
1	3	1	10
2	3	1.5	15
3	3.3	1	15
4	3.3	1.5	10

Figure 2. laser welded samples

Distortion is caused by the welding process's non-uniform heating and cooling. When using weldments, keep in mind that distortion may occur in both transverse and longitudinal orientations. Shape-based data analysis required consideration of thermal expansion, thermal conductivity, elasticity, & yield strength. Diffusion may be affected by a variety of factors apart than the material's physical characteristics, including the welding process itself.

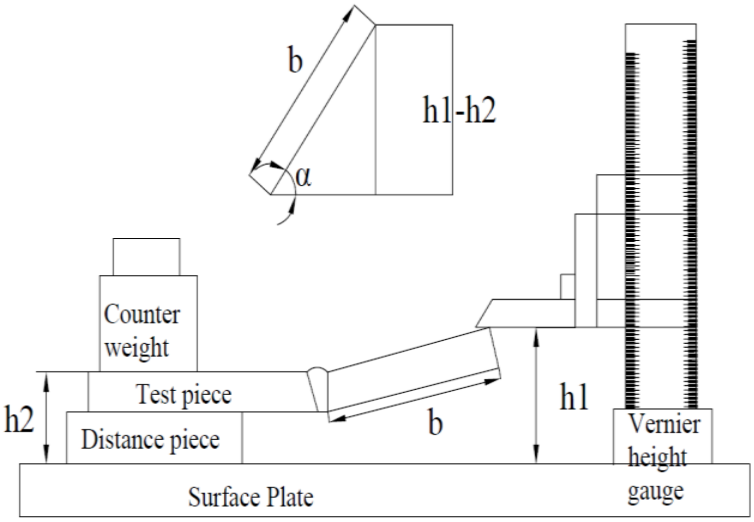


Fig. 3: Distortion was measured using a vernier height gauge.

3. Results And Discussions

3.1 Weld Quality

The weldment's aspect ratio was altered due to the controlled parameters. As illustrated in figure 4, the lateral surfaces of each joint were used to estimate the bead geometry, where both the joint's breadth and depth reside, to evaluate the internal quality of the weldments. A narrower bead width was recommended for weldments with deeper penetration. Trail-3 and Trail-4 trail welds have larger diameter bead diameters due to increasing laser power; this is seen in figure 4.

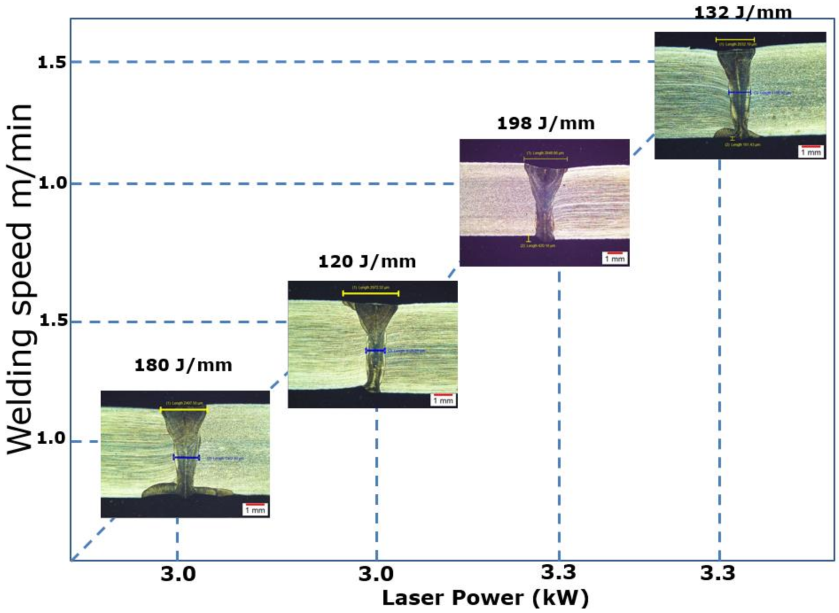


Figure 4 SS316L laser weldments macrostructure

Experiment count is N: 4, Figure 5 displays the mean and each distortion for four tests, with the response distortion and the mean all varying about to zero. The SSm (Sum of Squares of Mean) values are 10.27, and the Total Sum of Squares (SS_T) is 10.59. SS_e is 0.324 determined by multiplying these two principles by the Sum of Squares of Error (SSe), where SSe=SS_T-SSm. The variance of the parameters is calculated using the sum of squares. The experiment's objective is to design and determine the crucial parameters that will aid in achieving the desired results. The temperature and related responses, i.e., residual stresses, distortion from the welding process, have a minimum mean, and the lower, the better is recommended for increased cyclic operations. The authors identified the following parameters to obtain these outputs: Laser Power (LP kW), Welding Speed (WS m/min), and Shielding gas Flow Rate (SH lit/min). The chosen parameters may or may not be crucial; use a No-Way Anova approximation to determine if these parameters are critical or not.

Table-2 distortion in the weldments

No.	Welding process parameter			Response	
	LR kW	WD m/min	SH lit/min	Heat input j/m	Distortion
1.	3.0	1.0	10	180	1.83
2.	3.0	1.5	15	120	1.25
3.	3.3	1.0	15	198	1.93
4.	3.3	1.5	10	132	1.40

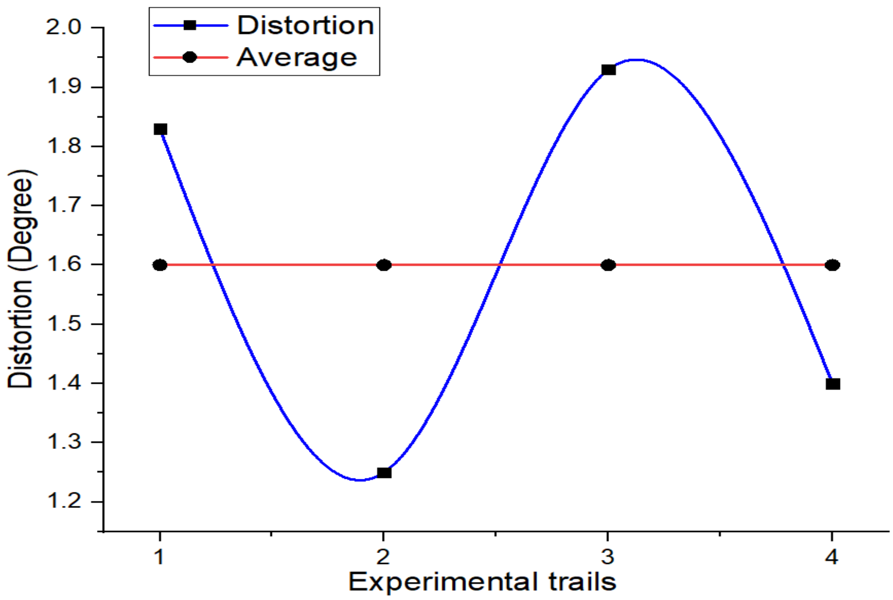


Figure:5 Distribution of distortion in the weldments

3.2. No Way ANOVA and ANOVA Summary

No way, there are two parameters in representing the data: mean and variance around the data. The chosen parameters are ineffective if the variance is slight, and we might have used essential parameters in our analysis if the variation is significant. The post-processing phase addresses the primary questions of how groups and conditions vary and how the relationship between certain groups and conditions affects the variables. This has no specification, so it's called "No Way" data analysis. The solution in this study is distortion, which must be as low as possible.

The F-test is a process contrast of a variance hypothesis test of importance suggested by Akella [24,25]. In No-Way ANOVA, the hypothesis consists among the differential between the average & errors. As an alternative to the F α, v_1, v_2, which compares the SSm, SSe ratio to the probabilities and (1- α) of the numerator's degrees of freedom (DOF), the SSm, SSe ratio may be calculated using the F, v1, v2. For a level of significant of (1- α), the alternative hypothesis is accepted if $F_{0.01}$, $v_{1,\,2}$ exceeds $F_{calculated}$.

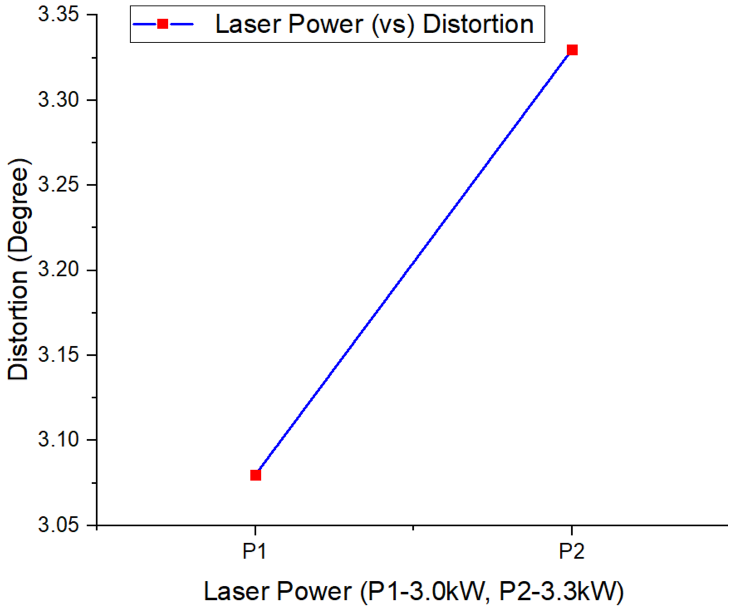
Table-3 No Way ANOVA

Source	SS	doF	Variance	Ftable	F0.1, 1, 3	F0.05, 1, 3	F0.01, 1, 3
Mean	10.27203	0.1	10.27203	95.03068	5.54	10.1	34.1
Error	00.324275	0.3	0.108092				
Total	10.5963	0.4					

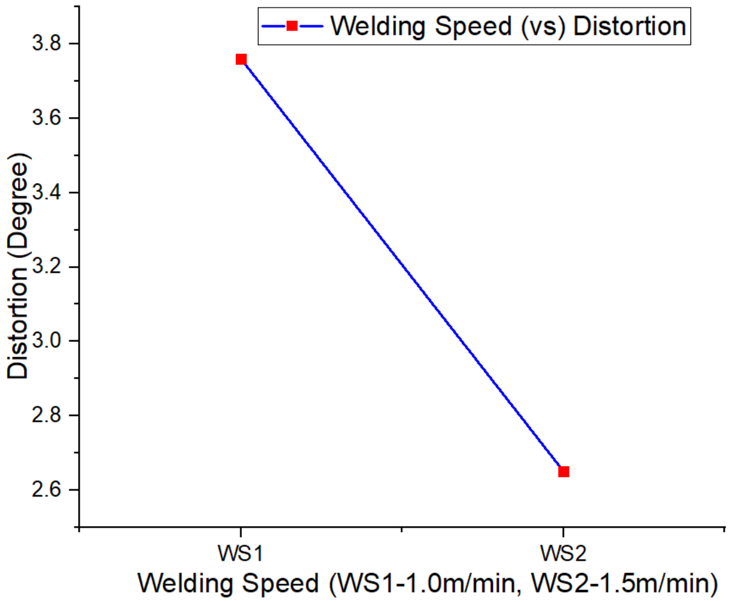
Table 4 ANOVA summary for distortion

Source	SS	doF, ν	Variance,V	F_{table}	F0.1, 1, 5	F0.05, 1, 5	F0.01, 1, 5	P, % Contribution
A, Laser power	00.015625	0.1	00.015	25	4.06	6.61	16.8	4.80
B. Welding speed	00.308025	0.1	00.308	492.84		++		94.80
C, Shielding gas	00.000625	0.1	00.000625	1				0.19
Error	00.000625	0.1	00.000625					0.19
SS_T	00.3249	0.4						100

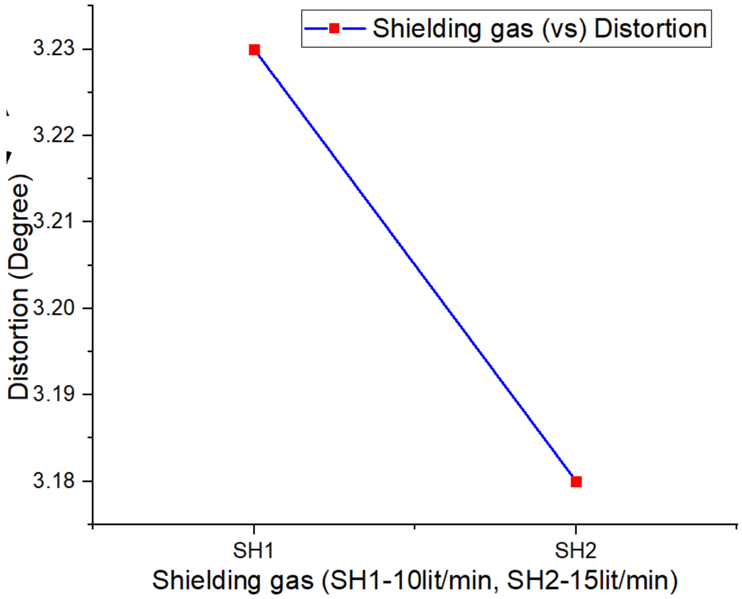
Taken from Table 3, we can assume the variation of mean and variance of error correspond to separate calculations because $F_{calculated}$ is better than $F_{0.05,1,3}$ and is also greater than F0.01,1,3 by 99% assurance. This value reflects a variance from the mean; it goes from zero to any important. Experiments would produce essential findings with a confidence level of 99%. As shown by the variance of 1.25 mm to 1.93mm across the mean value, the No-way ANOVA, the design of tests, parameter collection, and levels help define essential parameters.



(a)



(b)



(c)

Figure 6 Effect of process parameters on distortion

Table 4 shows the ANOVA description for the distortion effect parameters. Authors had concluded that factor B, welding speed, is significant because $F_{caluculated}$ is greater than $F_{0.01,1,5}$ and shielding gas selection is also essential towards monitor distortion with 95%. Level 2 has a distortion of 1.5m/min, which is 1.25° lower than level 1 of welding speed 1.0m/min, which has a distortion of 1.83°; as seen in Figure 6, the laser power of 3.3kW is not significant with both welding speed levels 1 and 2 and for least distortion at laser power 3.0kW is 1.48° at 1.5m/min welding speed level-2 is 2.65° and shielding gas at 15lit/min were distortion is 1.83°. As the correct response is lower the better, the welding speed at 1.5m/min, laser power at 3.0 kW produces low distortion, whereas level-2 of shielding gas 15lit/min has the least distortion but is not significant.

4. Conclusions

The SS316L was laser welded with varying laser capacity, welding speed, and shielding gas using a CO_2 laser process. According to radiography, the weldments are free of surface and internal defects.

- The Taguchi No-Way ANOVA was tested, and it confirmed with 99% certainty that the experiments had a primary parameter.
- Distortion was observed using a vernier height gauge, and only the welding speed parameter was critical with 95% confidence.
- For the least distortion, parameters can be used effectively when constructing structures using laser beam welding methods, Weld at level-2, Shielding gas at level-2 & laser power at level-1

References

[1] Anawa, E.M. and Olabi, A.G., 2008. Using Taguchi method to opti-mize welding pool of dissimilar laser-welded components. Optics & Laser Technology, 40(2), pp.379–388.

[2] Anawa, E.M. and Olabi, A.G., 2008. Using Taguchi method to opti-mize welding pool of dissimilar laser-welded components. Optics & Laser Technology, 40(2), pp.379–388.

[3] Deng, D., 2009. FEM prediction of welding residual stress and dis-tortion in carbon steel considering phase transformation effects. Ma-terials & Design, 30(2), pp.359–366.

[4] Deng, D. and Murakawa, H., 2008. FEM prediction of buckling distortion induced by welding in thin plate panel structures. Computational Materials Science, 43(4), pp.591–607.

[5] Deng, D., Murakawa, H. and Shibahara, M., 2010. Investigations on welding distortion in an asymmetrical curved block by means of numerical simulation technology and experimental method. Computational Materials Science, 48(1),pp.187–194.

[6] A. K. Dubey and V. Yadava.: Experimental study of Nd:YAG laser beam machining-An overview, Journal of Materials Processing Technology, vol.195, No.1–3, pp. 15–26, 2008.

[7] Moraitis, G.A. and Labeas, G.N., 2008. Residual stress and distortion calculation of laser beam welding for aluminum lap joints. Journal of Materials Processing Technology, 198(1-3), pp.260–269.

[8] Buddu RK, Chauhan N, Raole PM, Natu H. Studies on mechanical properties, microstructure and fracture morphology details of laser beam welded thick SS304L plates for fusion reactor applications. Fusion Engineering and Design; 2015,95:34–43.

[9] Subashini, L., Prabhakar, K. V. P., Gundakaram, R.C., Ghosh, S., and Padmanabham, G.: Single Pass Laser-Arc Hybrid Welding of Maraging Steel Thick Sections, Materials and Manufacturing Processes, vol. 31, No. 16, pp. 2186–2198, 2016.

[10] Vemanaboina H, Akella S, Kumar B. Distortion control in Laser beam welding using Taguchi ANOVA analysis. FME Transactions; 2020;48(2):180–6.
[11] Akella, S., Kumar, B.R. and Krishnaiah, Y., 2013. Optimisation of welding process parameters for distortion control with Taguchi ap-proach. International Journal of Precision Technology, 3(2), p.206.
[12] Harinadh Vemanaboina, G. Edison, Suresh Akella and Ramesh Kumar Buddu. Simulation of Hybrid Laser-TIG Welding Process Using FEA, Journal of Engineering Science and Technology, vol. 13, No. 6,1782 – 1792, 2018.
[13] H. Vemanaboina, G. Edison, S. Akella.: Distortion control in multi pass dissimilar GTAW process using Taguchi ANOVA analysis, International Journal of Engineering and Technology, vol. 7, No.3, p. 1140-1144, 2018.
[14] Genichi Taguchi and Yu in Wu.: offline quality, Central Japan quality Control Association, Nagaya, pp. 30-31, 1979.
[15] Phillip J Ross, Taguchi Techniques for Quality Engineering, Tata Mc Graw Hill, 2008.
[16] Ranjith Roy, “A Primer An Taguchi Methods”, Van Nostrand Rein-hold, Newyork, (1990).
[17] S. Marichamy, M. Ravichandran, B. Stalin, and S.Babu, “Optimization of abrasive water jet machining parameters for α-β brass using Taguchi methodology,” FME Transactions, vol. 47, no. 1,pp. 116–121, 2019.