Experimental investigation of the effect of variation in weld joint design for Single-J groove on mechanical properties of the weldment in SS304

[1]Nilesh Bhojani, [2]Pankaj R Rathod
[1]M.E Scholar, [2]Associate Professor
[1]Department of Mechanical Engineering,
[1]L.D College of Engineering, Ahmedabad, India

Abstract: The mechanical properties of a welded joint depend to a large extent on the geometry of the edge preparation. For the welding of thicker plates, edge preparation is necessary to ensure proper penetration, desired strength and to control weld distortions. The geometry of the edge preparation has an important consideration for the design and manufacturing of welded structures. Single-V groove type joint is most commonly employed for edge preparation, but for the plates having higher thickness (greater than 25 mm) this joint produces more angular distortions, residual stresses and less strength. For welding of thick plates, having thickness between 25 mm to 40 mm, Single-J joint is preferred. Geometric parameters of Single-J groove include groove angle, root gap and root face. The aim of this investigation is to investigate the effects of variations in geometric parameters of Single-J groove on mechanical properties and distortion characteristics of welded plates of stainless steel SS304 having thickness 25 mm. Welding was performed on TIG welding setup keeping all the other welding process parameters constant. The welded specimens were tested for tensile strength and bending test. Angular distortions in each welded specimen were also measured.

***IndexTerms* -** Weld Joint design, Single-J groove weld joint, Edge Preparation, Welding distortion, Root gap, Root face, Groove Angle.

I. INTRODUCTION

Welding is a joining process which is used to permanently join different materials like metals, alloys or plastics, together by application of heat and/or pressure. During welding, the work-pieces which are to be joined are fused at the interface and after solidification of the material a permanent joint can be achieved. Sometimes, an additional material is added to make a weld pool of molten material. It is called filler material. After solidification, it gives a strong bond between the materials. Filler material is required while welding of thick plates. Weld ability of a material is dependent on various factors like the changes in metallurgy that occurs during welding process, hardness changes in the weld zone caused due to faster solidification rate, the level of oxidation due to reaction of atmospheric oxygen with material. In the present scenario, welding has very vast application in process industry, fabrication maintenance industry, shipping industry, repairing of parts as well as structures.

When two thick plates of metals are to be welded together, it is required to prepare the edges first. A groove is formed on both or either of the plates where filler metal can be applied to form the joint. Preparation of this groove is necessary to ensure proper fusion, penetration, reduced weld distortions, to achieve required strength and desired metallurgical properties. Many a time, when the best suitable welding process parameters are chosen for welding, desired mechanical and metallurgical are not met. This problem occurs due to poor design of the weld joint or the groove. A large variety of groove shapes can be chosen depending on the requirements of the joint, thickness of the plate, nature of the joint, etc. The strength and quality of the weldment depends on the design of edge preparation [1]. In the design of a weld joint, the first consideration is its ability to transfer load, and the second is cost. The ideal weld joint is the one that can handle the load imposed, usually with a substantial safety margin, and still be produced at minimal cost [2].

Several investigators have examined the effect of different edge preparation on the strength of the weld joint. V Vara Prasad and D Lingaraju performed welding of butt type of single V, double V and single Y type of edge preparation for different groove angles [1]. After performing tensile tests for each specimen, it was concluded that groove angle had significant effect on the strength of the joint. Varun Sharma and A.S. Shahi prepared three different types of edge geometries having Double V butt joint, Double U butt joint, and Composite butt joint. From the impact test and tensile strength tests, it was observed that edge preparation had a significant effect on the impact strength and tensile strength of the welded joint [3]. Yanhong Ye studied the influence of groove type on welding-induced residual stress, deformation and width of sensitization region in a SUS304 steel butt welded joint [4]. Leijun Li performed experiments using 5 different V-groove angles 0°, 25°, 50°, 75° and 90° [5]. It was seen that the joint design had a significant effect on joint strength. Yunfei Meng investigated the effects of groove parameters on space constraint of narrow gap laser-arc hybrid welding [6]. Jastej Singh studied the influence of weld joint design and post weld thermal aging treatments on the metallurgical, intergranular and pitting corrosion behavior of AISI 304L stainless steel welded joints [7]. Z. Jitendra studied the effect of different groove angles for V-groove on height, width and penetration of the joint [8]. G. Turichina studied the influence of the gap width and speed of the welding on the changes of the geometry in the welded joint in the hybrid laser-arc welding of shipbuilding steel RS E36 [9]. Mrs.Sanap Deepali studied the effect of welding speed and groove angle on tensile strength of V-groove butt joint [10].

Another important consideration in weld joint design is wedding distortion. Distortion in welding is the undesired physical change in the shape of the welded specimen. Distortion is inevitable after welding but it can be minimized by following standard welding and heat treatment practices. The main reason behind the angular distortion in welding is the induction of thermal stresses due to heating and cooling cycles during welding. The angular distortion depends on co-efficient of thermal expansion of material [11]. Dean Deng studied the influence of deposition sequence on welding residual stress and deformation in an austenitic stainless steel J-groove welded joint [12]. Mahendramani G investigated the effect of root opening, Root face and groove angle on the distortions in the welded structure [13].

II. EXPERIMENTAL PROCEDURE

2.1 Selection of work piece material

Stainless steels are known for their corrosion resistant. Among the different types of stainless steels, austenitic stainless possess very good weldability. Due to its good weldability, it is widely used in structural applications, shipping industries, pressure vessels, etc. In this work, stainless steel of grade SS304 is used for experimentations. As the Single-J joint is preferred for the plate of thickness greater than 25 mm, the plate thickness for conducting the experimental investigation is taken as 25 mm. The dimensions of each plate which were welded together is 150mm × 150mm × 25mm. SS 316 mainly consists of iron (Fe) and other materials are added to modify its properties. A spectrography test was performed to know the chemical composition of base metal considered for the present study. Composition of 316 grade steel is shown in Table 1.

Table 1: Chemical composition of SS304

Element	% C	% Si	% Mn	% P	% S	% Cr	% Ni
Required minimum value	0.080	1.00	2.00	0.045	0.030	18-20	8.00-11.00
Value obtained from spectro test	0.059	0.358	0.942	0.028	0.008	18.332	8.012

2.2 Selection of Geometric parameters for Single-J groove

The present work focuses on the investigation of the effect of variation in geometric features of weld joint design for single-J groove on mechanical properties of the weldment in stainless steel. Figure 1 shows the geometry of single-J groove joint.

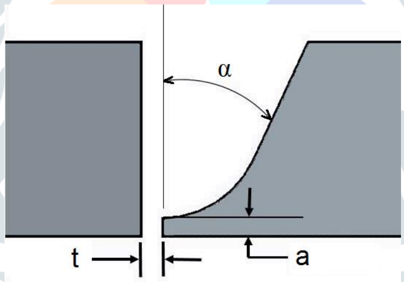


Figure 1: Geometric features of the Single-J groove

As per ASM handbook volume 06A [14] basic configuration for Single-J joint is as shown in figure 1. The geometric features of the single-J joint include root gap (t), root face (a) and groove angle (α). ASM provides the range of the values of geometric features of the joint within which one can design the joint according to the need of the joint. Groove radius is always kept ½ inch (12.7 mm). Root face, root gap and groove angle can be varied according to the need of the joint. Maximum value of root gap is 4.76 mm and for GMAW it is 2.38 mm. The value of root face is kept between 1.6 mm and 4.7 mm. As the intention of this study is to investigate the effects of geometric parameters of groove on the strength, all the other welding process parameters were keep constant. Three levels of all three factors were considered. The values of these levels are as shown in the Table 2. Range of all these factors were decided referring ASM handbook for welding [14].

Table 2: Levels of the Geometric variables

Factor	**Level -1**	**Level 0**	**Level 1**
Groove angle	15°	25°	35°
Root gap (t)	1.5	2.5	3.5
Root face (a)	1.6	2.6	3.6

2.3 Selection of Experimental design

Design of Experiments (DOE) is aimed to identify the significant active factors and investigate their effects on the output responses. Box Behnken design is used for conducting experimental runs. Here we have total 3 factors. All three are continuous variables with three levels. According to the Box Behnken total 15 experimental runs should be carried out. Table 3 shows a three variable Box– Behnken design.

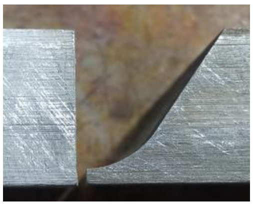
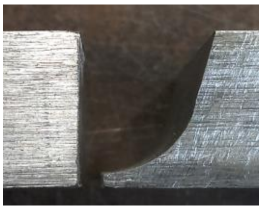
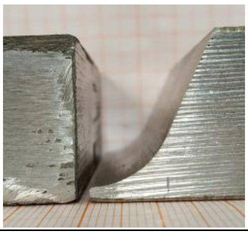
Table 3: Values of the variables of the matrix of experiments.

Std. order	Run	Coded variable			Real variable		
		Groove angle "A"	Root face "B"	Root Gap "C"	Groove angle "α"	Root face "a"	Root Gap "t"
1	14	-1	-1	0	15°	1.6	2.5
2	9	1	-1	0	35°	1.6	2.5
3	13	-1	1	0	15°	3.6	2.5
4	2	1	1	0	35°	3.6	2.5
5	15	-1	0	-1	15°	2.6	1.5
6	5	1	0	-1	35°	2.6	1.5
7	4	-1	0	1	15°	2.6	3.5
8	3	1	0	1	35°	2.6	3.5
9	7	0	-1	-1	25°	1.6	1.5
10	10	0	1	-1	25°	3.6	1.5
11	6	0	-1	1	25°	1.6	3.5
12	12	0	1	1	25°	3.6	3.5
13	8	0	0	0	25°	2.6	2.5
14	1	0	0	0	25°	2.6	2.5
15	11	0	0	0	25°	2.6	2.5

2.4 Preparation of Single-J groove

According to the set of experimental parameters generated by Design of Experiment method for 15 different runs as stated above, the corresponding Single-J joint grooves were prepared using wirecut EDM machine. All these 15 groove designs are shown in Table 4.

Table 4: Different Joint geometries fabricated according to DOE

 Joint-1	 Joint-2	 Joint-3	 Joint-4	 Joint-5
 Joint-6	 Joint-7	 Joint-8	 Joint-9	 Joint-10
				

Joint-11	Joint-12	Joint-13	Joint-14	Joint-15

2.5 Experimentation

Tungsten inert gas (TIG) welding setup was used in this work. TIG equipment consists of a welding torch that uses a non-consumable electrode made of tungsten, a welding power supply with constant current characteristics, inert gas cylinder (In our case, Argon). The welding process was to be done manually by worker so constant current power source is utilized to compensate the variation in gap between electrode and work piece. Zirconionated tungsten electrodes having diameter 3.4 mm were taken as an electrode. The end of the electrodes was made sharp using grinder. After every 3 to 4 passes the welded section was allowed to cool down up to around 100°C. Figure 2 Shows the TIG welding setup and fixture of the work piece on work table.

(a) (b)

Figure 2: (a) Experimental Setup for TIG welding, (b) Fixture of the work piece

Welding process parameters that were kept constant are presented in **Table 5**,

Table 5: Welding Process parameters.

Voltage	17V
Current	170 A
Current type	AC
Gas flow rate (Argon)	10 lit./hour
Electrode	ER316 1.6 mm diameter

As generated from DOE matrix, all 15 experiments were performed keeping all the welding process parameters constant. Plates that were utilized in the experiments were having the dimensions 150mm × 75mm × 25mm. Figure 3 shows the welded samples after performing all 15 experiments as specified by DOE.

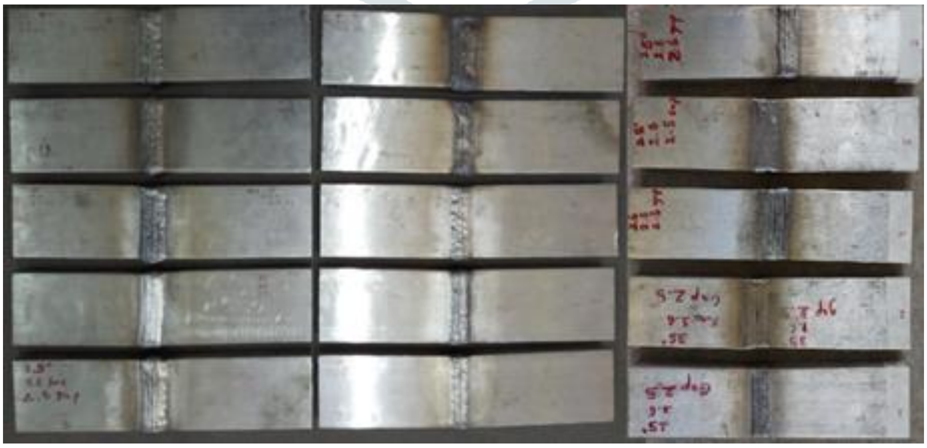


Figure 3: Welding samples

2.6 Tensile strength Testing

As per ASME section IX, specimens for tensile tests were prepared. According to the standard, the full thickness specimen were be used for thickness less than 25mm. As per ASME section IX [15] test specimen should be free from reinforcement caused due to welding. So the reinforcement from both top and bottom sides were removed using grinder before preparing the specimen. Figure 4 shows the prepared samples for tensile testing.

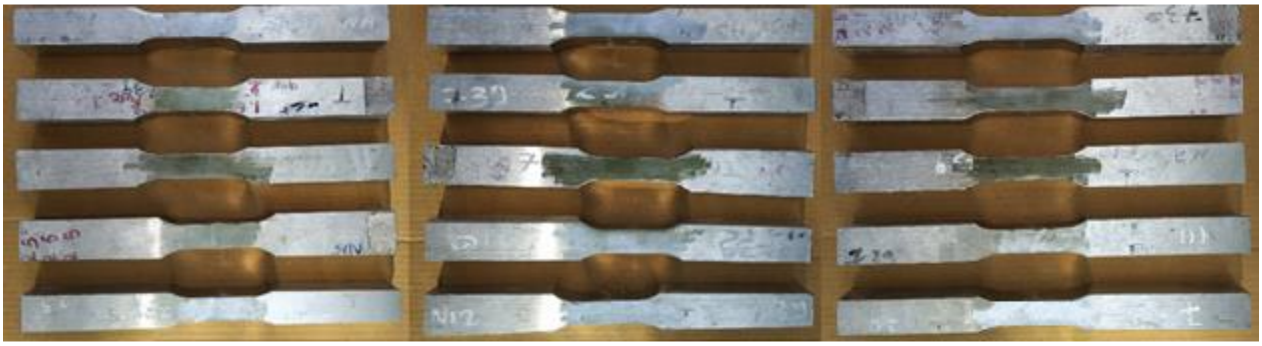
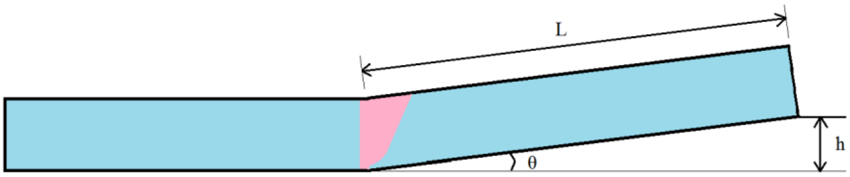


Figure 4: Prepared specimens for Tensile test

2.7 Angular distortion measurement

The angular distortion in present study was measured using sine bar principle. The specimen is placed on the flat surface as shown in Figure 5. The distorted side now makes an angle with horizontal surface. This angle is measured using the height of plate end and plate length. This is represented in the Figure 5.



$$\sin \theta = \frac{h}{L}$$

Figure 5: Measurement of Angular distortion in welded plates

III. RESULTS AND DISCUSSION

Using Design expert software (Version 10.0), the experimental data points were analyzed through Analysis of variance (ANOVA) and Lack of fit test. Mathematical modeling was carried out to find the relation between response variables and input parameters. Table 6 presents the input parameters and output responses for all experiments. Using Design expert software relationship between input parameters and output responses were obtained.

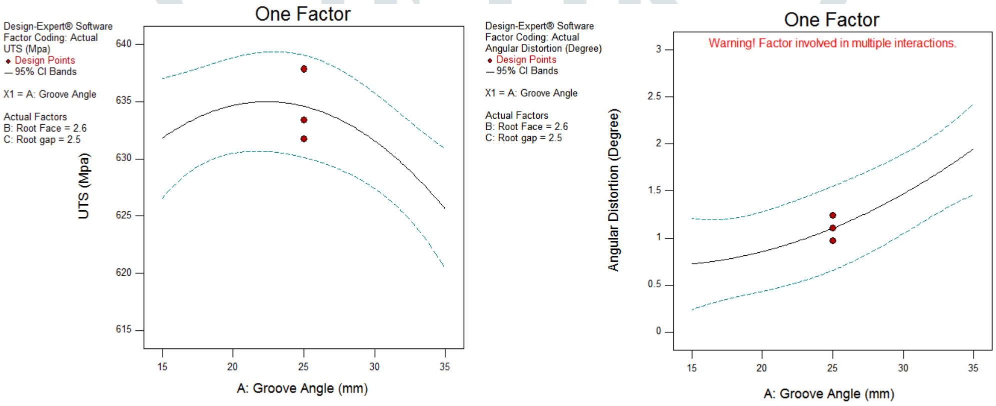
Table 6: Experimental results of Ultimate Tensile strength, Angular distortion and Filler metal consumption

Std. order	Run	Input parameters			Output Responses	
		Groove angle "α" (Degree)	Root face "a" (mm)	Root Gap "t" (mm)	Ultimate Tensile strength (N/mm2)	Angular distortion (Degree)
1	14	15°	1.6	2.5	629.105	2.02
2	9	35°	1.6	2.5	619.848	0.77
3	13	15°	3.6	2.5	637.539	1.85
4	2	35°	3.6	2.5	629.1	1.68
5	15	15°	2.6	1.5	621.105	0.71
6	5	35°	2.6	1.5	618.715	2.02
7	4	15°	2.6	3.5	627.891	1.12
8	3	35°	2.6	3.5	623.119	1.1
9	7	25°	1.6	1.5	625.634	2.72
10	10	25°	3.6	1.5	625.943	1.32

11	6	25°	1.6	3.5	637.03	1.24
12	12	25°	3.6	3.5	627.43	1.7
13	8	25°	2.6	2.5	631.733	2.54
14	1	25°	2.6	2.5	637.821	1.75
15	11	25°	2.6	2.5	633.353	2.36

3.1 Effect of groove angle on Ultimate tensile strength and angular distortion

The effect of groove angle on UTS and Angular distortion is shown in Figure 6. (a) and (b) respectively. With increase in groove angle, Ultimate tensile strength increases first, then it becomes maximum for fixed values of root gap and root face. Then it starts decreasing with increase in value of groove angle. At lower groove angle, filler metal consumption is less. That indicates less heat input to the weldment and faster cooling of weldment. At larger groove angle, filler metal consumption is higher. Higher amount of filler material will require higher amount of heat addition to the weldment and higher thermal residual stresses. So the value of Ultimate tensile strength decreases at higher groove angle. Welding Distortion is directly related to amount of material fused at the joint and face area of the joint. With increase in groove angle, both filler metal consumption and face area increases. Hence the angular distortion also increases with increase in groove angle.

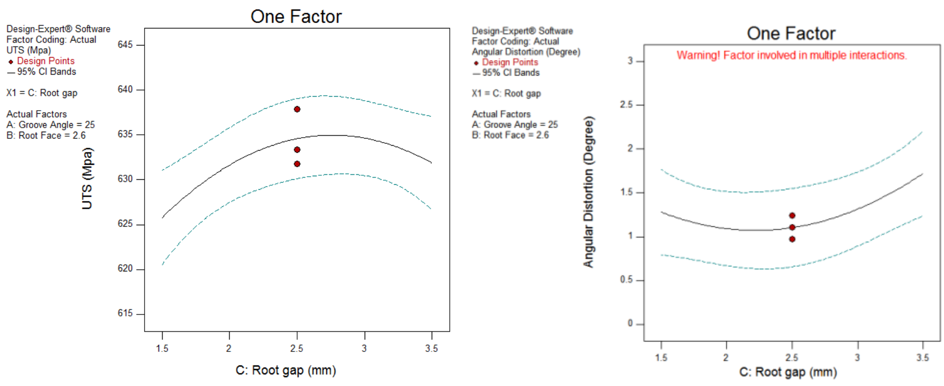


(a) (b)

Figure 6: (a) Effect of Groove angle on Ultimate tensile strength, (b) Effect of groove angle on Angular distortion

3.2 Effect of root gap on Ultimate tensile strength and angular distortion

The effect of root gap on UTS and Angular distortion is shown in Figure 7. (a) and (b) respectively. Effect of variation in root gap has similar effect like variation in groove angle. With increase in root gap, the filler metal consumption increases. At higher filler metal consumption, higher heat input is observed which decreases the UTS of weld join. With very narrow root gap, proper fusion and penetration cannot take place which decreases its UTS. With increase in root gap, UTS increases first, then it becomes maximum and starts decreasing then. With increase in root gap, filler metal addition in joint increases. More material addition indicates more amount of shrinkages due to thermal stresses. Thus with increase in root gap, angular distortion slightly decreases first and then in starts increasing with increase in root gap.

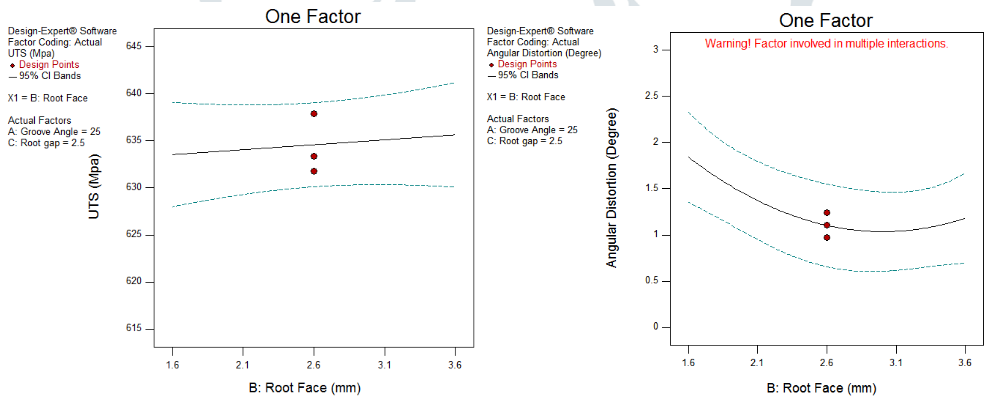


(a) (b)

Figure 7: (a) Effect of root gap on Ultimate tensile strength, (b) Effect of root gap on Angular distortion

3.3 Effect of root Face on Ultimate tensile strength and angular distortion

The effect of root face on UTS and Angular distortion is shown in Figure 8. (a) and (b) respectively. The effect of increase in root face on UTS is not much dominant. With increase in root face, UTS slightly increases. With increase in root facer the filler metal consumption in joint decrease. Which indicates lesser amount of shrinkages indicating lesser amount of angular distortion. Angular distortion first decreases with increase in root face, then in attains a minimum value and starts increasing again at higher value of root face.



(a) (b)

Figure 8: (a) Effect of root gap on Ultimate tensile strength, (b) Effect of root gap on Angular distortion

IV. CONCLUSIONS

The present study investigated the effect of variation in groove geometry of Single-J groove joint on mechanical properties of the joint. Stainless steel plates of grade SS304 having 25 mm thickness were considered for the investigation. Following conclusions can be made from the investigation;

- Groove angle, Root gap and root face have a significant effect on Ultimate tensile strength and angular distortion of weld joint.
- Among Groove angle, Root gap and root face, the effect of groove angle and root gap are more dominant.
- UTS of weld joint increases with groove angle up to certain limit, then it attains maximum and starts decreasing for too large values of groove angle.
- The effect of root face on UTS of weld joint is very less dominant.
- Angular distortion in welded plates significantly increases with increase in groove angle. Effect of groove angle on angular distortion is more dominant compared to other two geometric parameters under consideration.
- Angular distortion decreases with increase in root face up to a certain limit, attains a minimum value and slightly increases for higher value of root face.
- Angular distortion slightly increases with increase in root gap.

REFERENCES

[1] V. V. Prasad and D. Lingaraju, "Effect of Different Edge Preparations on the Tensile and Hardness Properties of Gtaw Welded 6082 Aluminum Alloy," Mater. Today Proc., vol. 4, no. 2, pp. 157–165, 2017.

[2] ASM Handbook, Volume 06A Welding Fundamentals and Processes.

[3] Varun Sharma, A.S. Shahi "Effect of groove design on mechanical and metallurgical properties of quenched and tempered low alloy abrasion resistant steel welded joints" Materials and Design 53 (2014) 727–736.

[4] Yanhong Ye, Jianpeng Cai, Xiaohua Jiang, Deping Dai, Dean Deng "Influence of groove type on welding-induced residual stress, deformation and width of sensitization region in a SUS304 steel butt welded joint" Advances in Engineering Software 86 (2015) 39–48.

[5] Leijun Li, Kevin Orme, and Wenbin Yu "Effect of Joint Design on Mechanical Properties of AL7075 Weldment" JMEPEG (2005) 14:322-326.

[6] Yunfei Meng, Geng Li, Ming Gao, Xiaoyan Zeng "Effects of groove parameters on space constraint of narrow gap laser-arc hybrid welding" Journal of Manufacturing Processes 33 (2018) 144–149.

[7] Jastej Singh, A.S. Shahi "Weld joint design and thermal aging influence on the metallurgical, sensitization and pitting corrosion behavior of AISI 304L stainless steel Welds" Journal of Manufacturing Processes 33 (2018) 126–135 **[2]** Basu, S. 1997. The Investment Performance of Common Stocks in Relation to their Price to Earnings Ratio: A Test of the Efficient Markets Hypothesis. Journal of Finance, 33(3): 663-682.

[8] Z. Jitendra, CH. Karthik sai , M. V. B. Sampath "Effect on width, height and penetration of V-groove butt joint weld bead by varying process parameters" International Research Journal of Engineering and Technology (IRJET) Volume: 04 Issue: 12, Dec-2017.

[9] G. Turichina, I. Tsibulskiya, M. Kuznetsova, A. Akhmetova, M. Mildebrathb, T. Hasselb "Influence of the Gap Width on the Geometry of the Welded Joint in Hybrid Laser-Arc Welding" Physics Procedia 78 (2015) 14 – 23.

[10] Mrs.Sanap Deepali , Dr. Dhamejani C.L , Prof. Burkul R.M "Influence of welding speed and groove angle on strength of V-groove butt weld joint using tig welding" International journal of engineering sciences & research technology 4(3): March, 2015.

[11] Pan Michaleris; Minimization of Welding Distortion and Buckling; 1st edition; Woodhead Publishing; 2011.

[12] Dean Deng "Influence of deposition sequence on welding residual stress and deformation in an austenitic stainless steel J-groove welded joint" Materials and Design 49 (2013)1022–1033

[13] Mahendramani, G. ; Swamy, N. Lakshmana "Effect of Root opening on Distortion of Butt-Joints in Submerged Arc Welding" Indian Welding Journal . Jan2016, Vol. 49 Issue 1, p48-56. 9p.

[14] ASM Handbook, Volume 06A Welding Fundamentals and Processes.

[15] Handbook, ASME section IX;