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FEM based Optimization of stress and deformation of lap joint using different materials S275, Al6061 and EN8 through ANSYS & Minitab

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Abstract- The objective of any industry is production of high quality products at low cost and increase the production rate. Welding is most important operation in any industry. It is essential to optimize the various parameters viz; welding current, welding speed, voltage, gas flow rate, etc. and also optimize mechanical properties viz stress , strain and deformation of welded joint . so that we can achieve the reliability, productivity and quality of the products. In this present study, the effective way is used to evaluate and optimise the welding techniques with better tensile strength for Lap Joint. The method opts for analysis of Lap welding joint is Taguchi method. Taguchi method is used for the purpose of result optimization. ANOVA method is used for proper judgement of result along with Taguchi method. The stress and deformation is calculated on the ANSYS software.
Keywords- Analysis of .Variance (ANOVA),Signal to Noise Ratio (SNR) ,Taguchi method , tensile strength, Welded Joint .

I. INTRODUCTION

Modern welding technology started just before the end of 19th century with the development of methods for a generating high temperature in localized zone. Welding generally requires a heat source to produce a high temperature zone to melt raw material, though it is possible to weld two metal pieces without much increasing temperature.[1] As the demand for welding new materials and larger thickness components increase, mere gas flame welding, which was first known to the welding engineer, is no longer satisfactory and improved such as metal inert gas welding, tungsten inert gas welding, electron and laser beam welding have been developed. Welding is the process of joining two pieces of metal by creating a strong metallurgical bond between them by heating or pressure or both. [2] A welded joint is obtained when two clean surfaces are brought into contact with each other and either pressure or heat, or both are applied to obtain a bond.

Working of Weld

For Joining Metals: By the usage of filler or joining materials, welding process is used to melt the base metal as well which is not been possible to melt via. usage of brazing and soldering. Heating the parent metal to melt it in order to make a joint stronger than the own parent metal. Along with this shielding gas is also being used to avoid contamination of filler metals.

For Joining Plastics: This type of welding uses heat to join the plastic materials expect in case of Solvent Welding. Firstly, before applying heat and pressure at the surface, it's been prepared and allowed to cool down in order to get the attachment. It's completely dependent on the external and internal ways of heating for melting plastics.

For Joining Wood: It uses heat generated from friction to join the materials. The materials to be joined are adhere to a great deal of pressure before a linear friction movement creates heat to bond the work pieces together.[3]

Taguchi Method

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.[4]

Steps involved in Taguchi Method:

There are seven steps involved in Taguchi Method:

i. Identify the main functions, side effects and failure mode.
ii. Identify the noise factors, testing conditions and quality characteristics.
iii. Identify the objective function to be optimized.
iv. Select the orthogonal array matrix experiment.
v. Conduct the matrix experiment.
vi. Analyze the data, predict the optimum levels and performance.
vii. Perform the verification experiment and plan the future action.

II. LITERATURE REVIEW

P. K. Singh et al. [1] With an aim to improve the mechanical properties of a weld joint, a new concept of vibratory setup has been designed which is capable to stir the molten weld pool before it solidifies during shielded metal arc welding (SMAW) operation. Mechanical vibration having resonance frequency of 300 Hz and amplitude of 0.5 mm was transferred to the molten weld pool of 6 mm thick mild steel butt-welded joints during the welding operation. The experimental work was conducted at various ranges of frequencies, welding current and welding speed. Taguchi's analysis technique has been applied to optimize the process parameters; the response values for analysis are yield strength and micro-hardness. The test results showed that with the application of the vibratory treatment the values of hardness and tensile properties increased. The auxiliary vibrations induced into the weld pool resulted in increased micro-hardness of the weld metal which indicates the orientation of the crystal and refinement of grains took place. This study shows that vibration applied into the weld pool can be successfully improved the mechanical properties of welded joints. Thus this research attempt provided an alternative welding technique for grain refinement of weldments.

Umangkumar et al. [2] According to author, Welding is an economical process used for joining metals. The process parameters of welding have considerable effect on the productivity and costing of the resulting assembly. The project work dealtwith optimizing the welding parameters and reducing welding time for the conveyer pulley being welded by submerge arc welding (SAW) technique. Due to variations in the welding parameters there are problems of punctures and other surface defects. By optimizing the welding parameters, the problem of punctures can be eliminated and other defects can be reduced. This will reduce the overall welding time as well as manufacturing time of the conveyor pulley assembly leading to increase in productivity and reduction in manufacturing cost. This can be achieved by performing experiments by keeping the electrode material, welding speed, electrode stick out, electrode diameter as constant & varying the welding current, arc voltage & stand-off distance. The effects of varying these variables were studied by adopting Taguchi Method. This would result in the optimization of the said variables.

Borkar et.al [4] The present study deals with the effect of controllable factors mainly rotational speed, Welding Speed & Shoulder to pin diameter on Tensile strength in FSW operation. The experiments were performed on dissimilar material Al-Cu plates Using Taguchi method. A three level, three Factor design of experiment prepared according to Taguchi orthogonal array L9 using Minitab 16 software. The Analysis of Variance (ANOVA) and Signal to Noise (S/N) Ratio was carried to find out the most significant factor and percentage contribution of individual factor for Tensile strength. From result it is found that optimum level for Tensile strength is obtained as 2000 rpm of rotational speed, 70 mm/rev of welding speed and 5.5 of Shoulder to pin diameter. From result it is also observed that rotational speed is the most contributing factor with contribution of 70.44%.

H.Li et.al [5] Author analysed that for joining the thin metallic sheets, spot welds are used in aerospace as well as automotive industries. Propogation of fatigue cracks is the basic failure of spot welding which is nucleated around the edge of weld nugget. For the prediction of fatigue life, fracture mechanics analysis is used which is based on the “stress intensity factor”. Fracture mechanics analysis plays important role in analysing the durability of vehicles. It becomes significant to attain high fiedility SIFs with the spot weld edges.

Marcello Lepore et.al [6] According to author, in the welded strictures, for simulating the 3-d crack propagation, a numerical procedure is proposed on the basis of Finite element method. In a friction stir welded AA2024-T3 butt joint, cracks are introduced which are affected by the “process-induced residual stress scenario”. “Thermo-mechanical FEM simulation” inferred the residual stress field. In this study, material softening properties, elastic plastic material properties are taken into considerations which are temperature dependent.

Patil et.al [7] Author suggested that Gas metal arc welding (GMAW) is widely used in manufacturing company for good quality of welding. In this research work of GMAW show the effect of Current (A), Voltage (V) and Speed (IPM) on tensile strength of S355J2N steel material. In this design of experiment we have done experiment by using Taguchi method. One of the important welding output parameter in this process is Tensile Strength. A total number of 9 experiment runs are conducts using an L9 orthogonal array for optimization of welding parameter levels of Current, Voltage and Speed. Calculate the signal-to-noise ratio and obtain optimum level for each input parameter. By using ANOVA the significant coefficients for each parameter on tensile strength are determine.

Feng-yuan SHU et.al [8] For narrow gap CMT “Finite element method” model is generally applicable. On the basis of interactions in between the filler metal, base metal and arc, CMT+P MIX welding were designed. Under the conduction of equivalent output, a method for “heat input pulses” and “simplifying wire feeding pulses” was supposed. The method together with composed double-ellipse heat sources was included in the model. The model was employed in the investigation of thermal cycling and the identification of the softened zone of AA7A52 base plates. Low-frequency behaviour emerged in the form of low-cooling rate sects, which were not expected under experimental conditions.

Yupiter H.P. et.al [9] In this study, an investigation is presented in which FEM is used and the experimentation is performed which shows the welding sequence effect on the induced angular distortion. In SYSWELD 2010, “Multipass Welding Advisor (MWA)” is used for modelling the specimen of the combined joint geometry and for simulation on the basis of “thermal-elastic-plastic approach”. In this, as a heat source model, Goldak’s double ellipsoid is used and as a specimen material, low manganese carbon steel S3355J2G3 is used. To validate the simulation results, a series of experiments was conducted with two different welding sequences using automated welding process, low carbon steel as parent metal, digital GMAW power source with premixed shielding gas and both-sided clamping technique. “Simulation of complex welding process” is not considered as the easy task as it requires the interaction of mechanical, metallurgical and thermal phenomenon.

Umang kumar et al. [10] Author analysed that for joining metals, welding is the best economical method. Considerable effects are observed on the costing and productivity of the resulting assembly. The welding parameters are optimized by the project work. And through “submerge arc welding (SAW) technique”, the welding time is also reduced. Problems such as puncture may be eliminated by optimizing the welding parameters. For enhancing the productivity and for reducing the cost, this is considered as the best tool for designing. The best advantage obtained from taguchi method is that it reduces the number of experimentations to be performed which saves lots of time. Only nine experiments can be performed and better results can be obtained by using this methodology.

Stalin et al. [11] According to author Welding technology is one of the fastest growing opportunities in the field of manufacturing engineering. Today, many construction, erection, ship building and body building works are not possible without welding. Although welding technology has many positive features, there are some negative features which are to be taken under consideration of this work. Many risks and accidents could be avoided, if the negative features of welding technology have been rectified. Many people involving in welding works are not able to identify the exact loading and boundary conditions for the corresponding weld, which is to be created by using design of experiment (DOE).. This paper deals with the analytical response approaches of lap joint weld with respect to the minimum and maximum loading parameters. In order to identify the boundary condition of mechanical parameters with respect to the weld this is to be created.

Asif Ahmad et al. [12] Author suggests that for “ferrous and non-ferrous”, a famous welding technique is the “tungsten inert gas welding”. In the manufacturing of stainless steel, “Stainless steel grade 3HQ (S30430)” is a specialized wire grade. For heading usage, it has replaced more than Grade 384 and 305. As a result, it shows excellent toughness which is even less than cryogenic temperature. On the basis of “Taguchi's design of experiments (DOE)” experiment were conducted and by using parameters like voltage, depth, current or speed, mathematical model was developed. In order to perform experiment for data collection following sequence is followed: Selecting the base and filler material, Selecting pulsed TIG welding process parameters, Finding the upper and lower limits of the identified process parameters, Select the appropriate orthogonal array, Conduction of the experiments as per the selected orthogonal array, Find the optimum condition.

Loureiro et al. [13] In recent years, several researchers have been working hard to improve the knowledge with respect to steel joints behaviour. Special effort has been made for obtaining the stiffness of the different components of the joints, with the aim of introducing this stiffness in the component method in accordance with the EC3. Nevertheless, the component method has important limitations and therefore it is necessary to develop new methods for obtaining the stiffness of joints. In the present work, an alternative method of evaluating the stiffness of 2D external welded haunched joints is presented. The authors show the results of 4 tests and their corresponding finite element models. Four different typologies of joints have been tested, in regards to the stiffening of the column web. Additionally, finite element models of the joints have been developed, and they have been properly calibrated with the results obtained in the tests.

Daniel Das et al. [14] In this research work, tool rotational speed was identified as the most influencing parameter in producing better joining strength. Generally, AA 7075 is concluded as an unfabricated metal and also the parent metal can’t be welded using fusion welding process. The chemical composition of AA 7075 was 0.4 % Si; 1.6 % Cu; 0.6 % Fe; 0.25 % Cr; 0.1 % Ti and balance of Aluminium base metal. The chemical composition of AA 6063 was 1.38% Si; 0.64% Cu; 0.98% Fe; 0.63% Zn; 0.49% Ti and balance of Aluminium base metal. The ranking process shows that the Feed rate was the most convincing parameter among three parameters that produces effective weld joints. According the levels, the feed rate secures 162.8 mm/min at its first level followed by 153.8 mm/min and 144.7 mm/min at level 2 and level 3 means values respectively.

Mandeep Singh et al. [15] The presented work suggests that the gas supplied gets ionized to form an arc between electrode and work piece, resulting in smooth welding. Continuous welding results in higher metal deposition rate as well as high welding speed. The filler wire is connected to positive polarity while work piece is connected to negative polarity. DOE is a technique introduced by R.A. Fisher in 1920. It is basically used to study the effects of multiple variables simultaneously. The collaboration of DOE with Taguchi proves to be efficient to ensure desired optimization. Welding current, voltage, gas flow rate, wire feed rate, diameter of electrode etc. are some of the important process parameters in MIG welding, in which welding current and voltage being the most significant.

They affect the weld quality in terms of mechanical properties and weld bead geometry. Welding current is directly proportional to the depth of penetration. The Taguchi method is an influential tool for improving the output response during research and development, resulting in better quality products in minimum time and cost.

III. METHODOLOGY

Steps of Method

1. Design of Experiment table by using L9 Orthogonal array table.
2. Further converting the File in .step format for importing it in Ansys Fluent work bench.
3. Assigning the Material property in parts.
4. Meshing for performing the simulation process.
5. Provide the suitable boundary conditions according to the decided objective.
6. Evaluating the results after the finish of simulation work.
7. After simulation the result is analysis in Taguchi method by using Minitab software

S/N Ratio Calculation

Smaller the better: It is used where the smaller value is desired

$$\text{S/NRatio} = -10 log \frac{1}{n} \sum_{i=1}^{n} y\, i^2 \qquad (1)$$

Where y = observed response value and n = number of replications.

Nominal the best: It is used where the nominal or target value and variation about that value is minimum.

$$\text{S/NRatio} = -10 log \frac{y^2}{\sigma^2} \qquad (2)$$

Where σ = mean and μ= variance.

Higher the better: It is used where the larger value is desired.

$$\text{S/NRatio} = -10 log \frac{1}{n} \sum_{i=1}^{n} \frac{1}{yi^2} \qquad (3)$$

Steps representing Taguchi Design:

Below figure exhibits the level of design and number of factors to be selected. Then press “OK” tab.

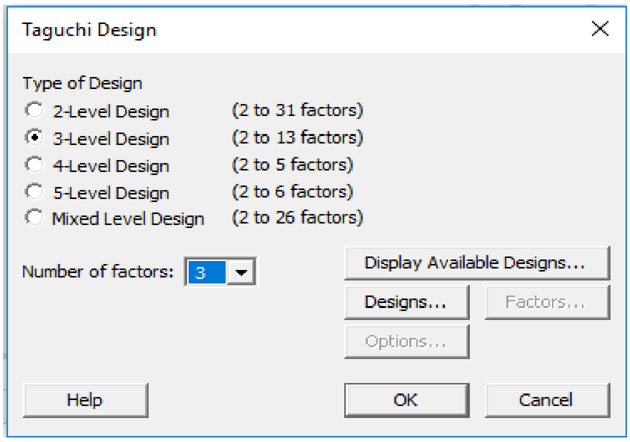

Figure 1: Level of design and number of factors

Below figure exhibits the orthogonal array as L9 and L27 and columns to be selected and then press "OK" button.

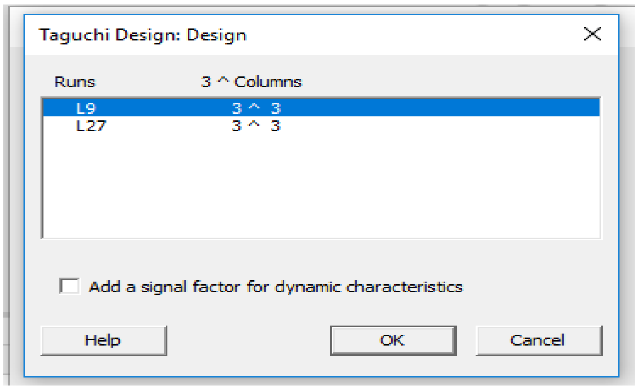

Figure 2: Selection of Orthogonal array as L9 and L27 and columns

I.1.1 Table showing Orthogonal L9:

Table 1: Table representing Orthogonal L9:

Case	Design	Force (KN)	Material
1	D1	108	S275
2	D1	128	Al6061
3	D1	148	EN8
4	D2	108	Al6061
5	D2	128	EN8
6	D2	148	S275
7	D3	108	EN8
8	D3	128	S275
9	D3	148	Al6061

I.1.2 Representation of Welding Design:

Lap welding joint is drawn with the help of software and two types of beam are used as IPE300 and HEA200 and joined together perpendicularly using software. Lap welding joint is presented here in three images, Figure for design 1 showing direct joint of beams perpendicularly, figure for design 2 showing curve joint perpendicularly, figure for design 3 showing rectangular joint perpendicularly.

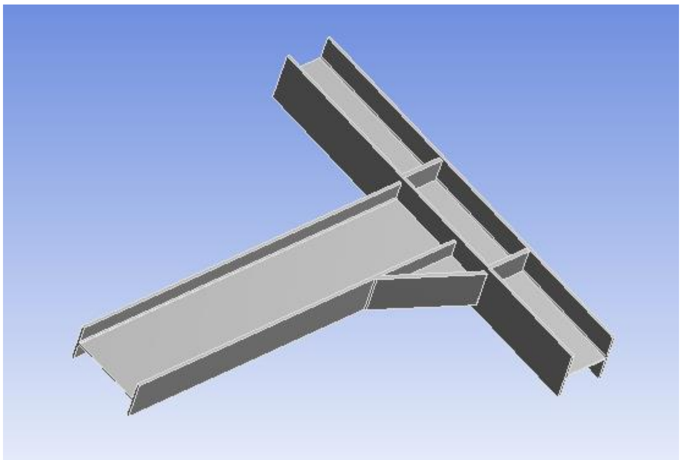

Figure 3: Design 1 showing direct joint of beams perpendicularly

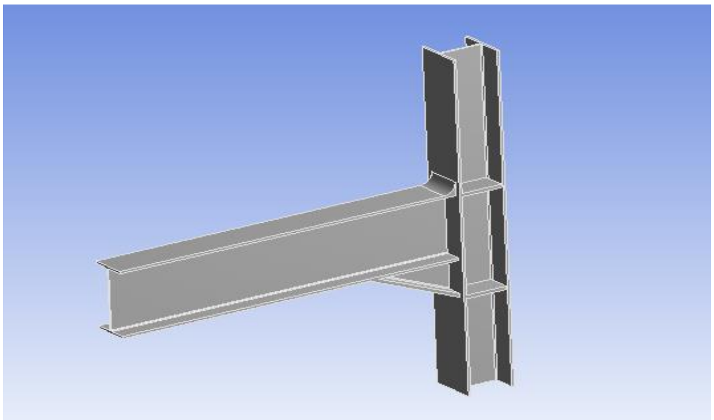

Figure 4: Design 2 showing curve joint perpendicularly

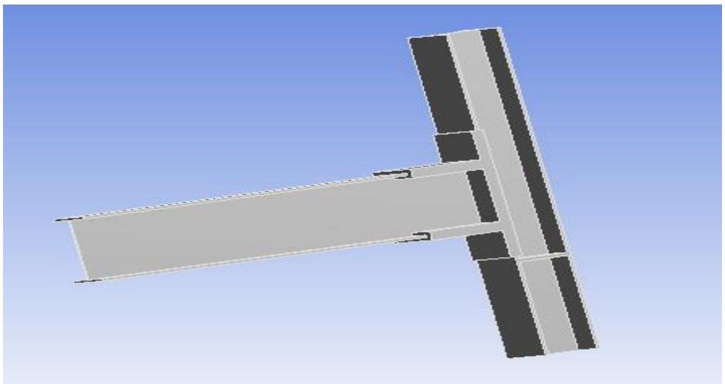

Figure 5: Design 3 showing rectangular joints perpendicularly

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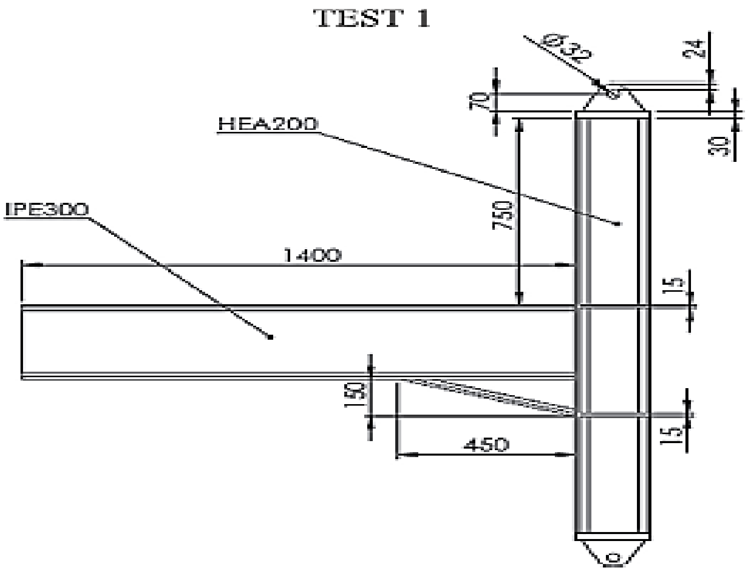

Figure 6: Representation of dimensions of the designs

Representation of Mesh Design:

Welded mesh is a type of barrier fencing which comes in rectangular or square designs. They are made of steel wire which is welded at every intersection. This kind of fencing is known to be better than chain link fencing because they cannot be cut easily especially if the wire thickness is thick. It is a superb option for high-security facilities. After analysing, Nodes determined is 784563 and Element determined is 468057.

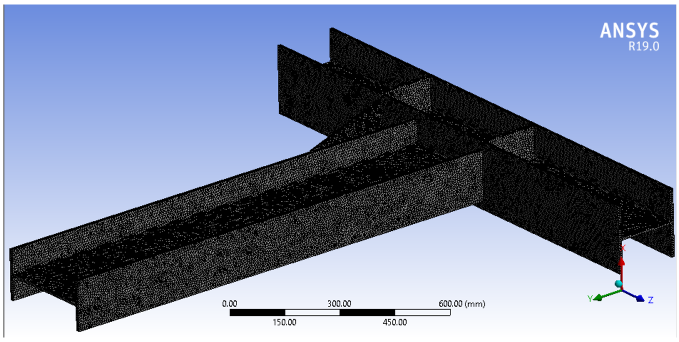

Figure 7: Representation of mesh design

Representation of Boundary Condition:

Boundary condition is being represented as the beam which is fixed at both of its end perpendicular to the beam force 128 KN which is applied as seen in the below image.

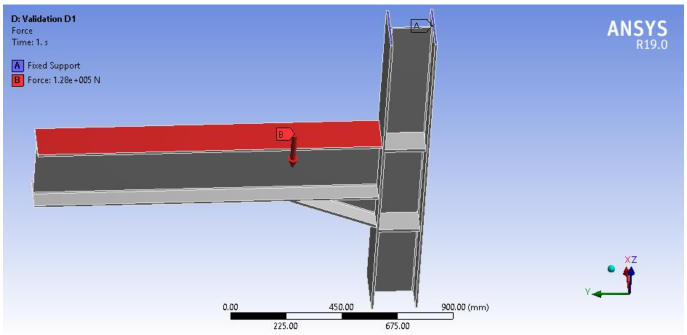

Figure 8: Representation of boundary conditions

Material used

S275 Steel

Structural steel is a basic construction material, made from specific grades of steel and manufactured in a variety of industry standard cross-sectional shapes (or 'sections'). Structural steel grades are engineered with specific chemical compositions and mechanical properties formulated for specific applications. Structural S275 steel plates are commonly used in most industrial construction, such as bridges, railways and ships etc. Consequently, it is crucial for industrial construction to establish the fatigue strength of material, in terms of stress and the number of cycles needed to fail, known as the S-N curve, for better design and to avoid unexpected failure in the material.

Structural steels are used in many ways and their application can be varied. They are particularly beneficial because they offer the unique combination of good welding properties with assured strengths. Structural steel is a very adaptable product and is frequently favoured by the engineer trying to maximize strength or structure while reducing its weight.

Al6061

6061 (Unified Numbering System (UNS) designation A96061) is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S", it was developed in 1935. It has good mechanical properties, exhibits good weld ability, and is very commonly extruded. It is one of the most common alloys of aluminum for general-purpose use. It is commonly available in pre-tempered grades such as 6061-O (annealed), tempered grades such as 6061-T6 and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).

EN8 Steel

EN8 carbon steel is a common medium carbon and medium tensile steel, with improved strength over mild steel, through-hardening medium carbon steel. EN8 carbon steel is also readily machinable in any condition.

EN8 steels are generally used in the as supplied untreated condition. But EN8 steels can be further surface-hardened by induction processes, producing components with enhanced wear resistance. Steel EN8 materials in its heat treated forms possess good homogenous metallurgical structures, giving consistent machining properties.

EN8 steel material is suitable for the all general engineering applications requiring a higher strength than mild steel such as:

- general-purpose axles
- shafts,
-
- spindles,
- automotive and general engineering components,
- Other general engineering parts etc.

Validation:

In comparison with the value of equivalent stress exhibited as 372.77 MPa in Alfonso Loureiro et.al. [13], this work attained a value of 368.54 MPa. There is a 1.073% difference among both the values which is very negligible.

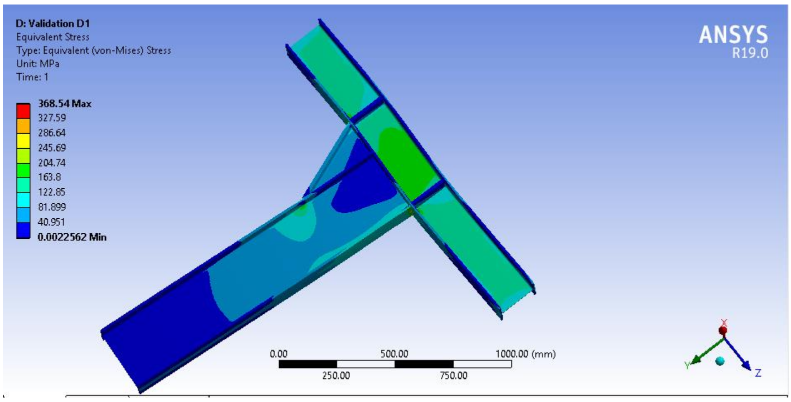

Figure 9: Equivalent stress in Validation D1

IV. RESULTS AND DISCUSSION

Calculation of S/N Ratio:

The table given below represents the responses of average values of input parameter setting. The responses of the three parameters are calculated by the signal-to-noise ratio. Higher values of tensile strength, elongation, and impact strength give better performance of welding.

Table 3: Table representing S/N Calculation Ratio:

Case	Design	Force	Material	Stress (MPa)	Deformation	S/N Ratio
1	D1	108	S275	310.95	4.62	-49.8538
2	D1	128	Al6061	362.45	16.87	-51.185
3	D1	148	E8	368.54	6.05	-51.3297
4	D2	108	Al6061	253.48	14.22	-48.0789
5	D2	128	E8	296.28	6.05	-49.434
6	D2	148	S275	342.58	6.33	-50.6952
7	D3	108	E8	283.48	6.54	-49.0504
8	D3	128	S275	335.98	7.02	-50.5263
9	D3	148	Al6061	388.47	8.97	-51.7871

Response Table 4: Representing Response Table

(Note: Smaller is better)

Level	Design	Force	Material
1	-50.79	-48.99	-50.36
2	-49.40	-50.38	-50.35
3	-50.45	-51.27	-49.24
Delta	**1.39**	**2.28**	**0.42**
Rank	**2**	**1**	**3**

S/N Ratio Graph:

Basically, the larger the S/N ratio, the better is the quality characteristic for the tensile strength. The response of S/N ratio with respect to tensile strength indicates the forging load to be the most significant parameter that controls the weld tensile strength where's the friction load, forging time & friction time are less significant in this regard.

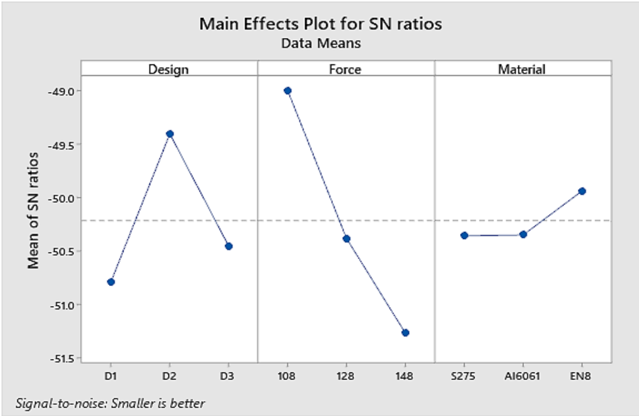

Figure 10: Main effects of plot for SN ratios

Figure shows variation of S/N ratio with respect to the forging load. As the forging load increases the weld strength also increases. Also friction time increases the weld strength were increased.

Result Validation:

Equivalent Stress: Equivalent stress is used when there is a multiaxial stress state with multiple stress components acting at the same time in the structure. In such case we can use selected criterion to transform the whole stress tensor into a single equivalent component that can be treated as a tensile stress and thus compared with material's strength easily.

In the figure given below, the result of Case 10 is shown. The result shows the maximum as well as minimum value of equivalent stress. 249.99MPa is the maximum and 0.0019633MPa is the minimum value observed.

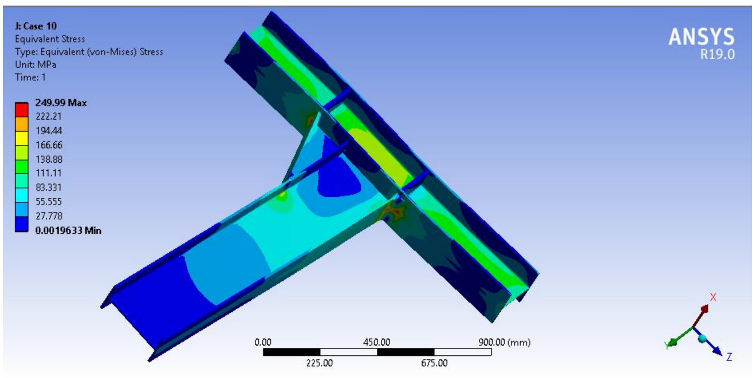

Figure 11: Equivalent Stress

Total Deformation: Deformation results generally can be in ANSYS Work Bench as total deformation or directional deformation. Both of them are used to obtain displacements from stresses.

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In the figure given below, the result of Case 10 is shown. The result shows the maximum as well as minimum value of total deformation. 5.1108mm is the maximum and 0.00mm is the minimum value observed.

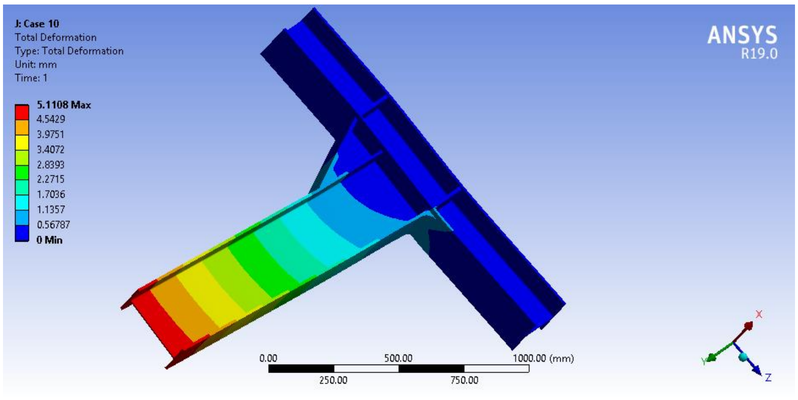

Figure 12: Total deformation

Stress Comparison:

Residual stresses (RS) are the stresses that get introduced during manufacturing processes such as cutting, cold work, welding, grinding, shot peening etc., Generally, tensile residual stresses on surfaces are undesirable as they decrease the fatigue strength. However, compressive stresses on surfaces improve the fatigue strength. Welding related stresses are of utmost importance and can be a major cause for failure of components.

Stress v/s Cases:

The graph shown below represents the value of stress in particular cases from Case 1 to Case 10. In case 9, the maximum value of stress is observed and Case 4 shows the minimum value for stress.

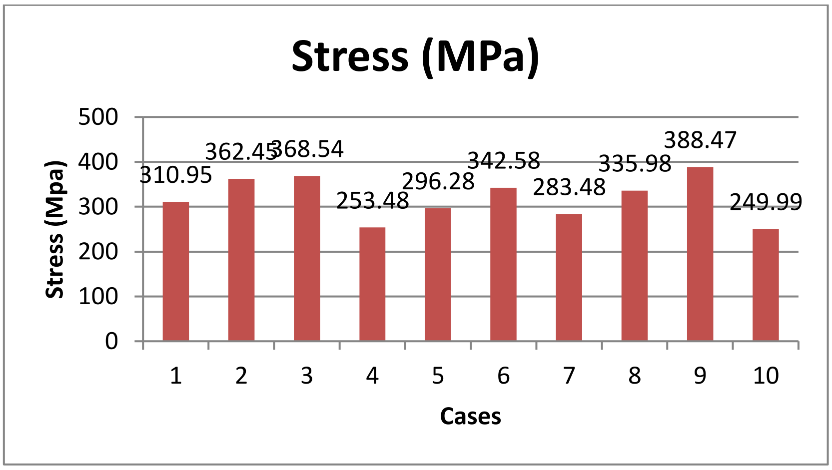

Figure 13: Graphical representation of Stress v/s Cases

Deformation v/s Cases:

The graph shown below represents the value of deformation in particular cases from Case 1 to Case 10. In case 2, the maximum value of deformation is observed and Case 1 shows the minimum value for deformation.

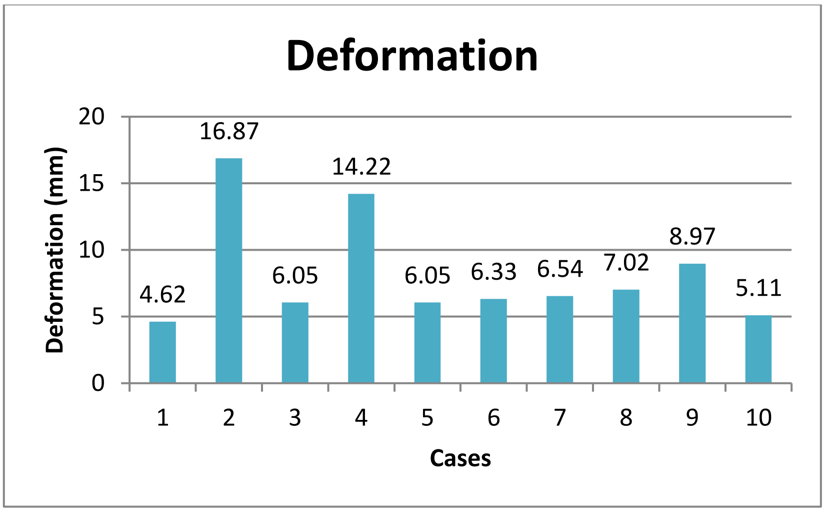

Figure 14: Graphical representation of Deformation v/s Cases

ANOVA Method for Analysis:

After performing the statistical S/N analysis, ANOVA needs to be employed for determining the relative importance of various factors. ANOVA demonstrates whether observed variations in the response are due to alteration of level adjustments or experimental standard errors. ANOVA as a common statistical method is also used to analyze the results of the experiments on response and also to determine contribution of each influencing factor. FE analysis is also carried out by considering the chamfer on vertical plate. The Maximum von-misses stresses present in T-joint weldment at the throat thickness with gap variation are carried out and the variation of Maximum breaking stress with respect to gap and angle is also shown in Table.6.3.

Table 5: Representing ANOVA Analysis:

Source	DF	Contribution	F-Value	P-Value
Design	2	26.31%	15.35	0.061
Force	2	68.37%	39.89	0.024
Material	2	3.61%	2.11	0.322
Error	2	1.71%	-----	-----
Total	8	100.00%	------	-----

Result Determination:

- After applying Taguchi method it is shown that Force is placed at first rank, Design at second and Material at third.
- For obtaining better result, Force of level 1, Design of Level 2 and material of level 3 is taken.
- After applying this combination, the lowest stress value is achieved which is 249.99 Mpa and the corresponding deformation value is 5.11 mm.
- ANOVA analysis show that Contribution of Design is 26.31%, contribution of force is 68.37% and contribution of material is 3.61%.

V. CONCLUSION

A statistical approach namely is design experiments a Taguchi's technique was utilized to plan and minimize the number of experiment, at the same time making reliable inference from the results. A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters. The finite element analysis is used in this work to evaluate the deformation breaking stress of weld T-joint to restrict the weldment failure (using low carbon steel as a base metal and copper filler material). The obtained results are compared with the FE analysis and both are acceptable. For the evaluation of maximum breaking stress, the experimental analysis is carried out.

VI. REFERENCES

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