Analysis on Flexural Strength of A36 Mild Steel by Design of Experiment (DOE)

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Abstract. Nowadays demand for high quality and reliable components and materials are increasing so flexural tests have become vital test method in both the research and manufacturing process and development to explain in details about the material’s ability to withstand deformation under load. Recently, there are lack research studies on the effect of thickness, welding type and joint design on the flexural condition by DOE approach method. Therefore, this research will come out with the flexural strength of mild steel since it is not well documented. By using Design of Experiment (DOE), a full factorial design with two replications has been used to study the effects of important parameters which are welding type, thickness and joint design. The measurement of output response is identified as flexural strength value. Randomize experiments was conducted based on table generated via Minitab software. A normal probability test was carried out using Anderson Darling Test and show that the P-value is <0.005. Thus, the data is not normal since there is significance different between the actual data with the ideal data. Referring to the ANOVA, only factor joint design is significant since the P-value is less than 0.05. From the main plot and interaction plot, the recommended setting for each of parameters were suggested as high level for welding type, high level for thickness and low level for joint design. The prediction model was developed thru regression in order to measure effect of output response for any changes on parameters setting. In the future, the experiments can be enhanced using Taguchi methods in order to do verification of result.

1. Introduction

Repair and maintenance activities are vital in an industry where components and segments that have been changed parts. The usage of repair welding is to restore the genuine condition, safe operation and long life service. The technique is most appropriate and usual for joining steel structure is in need of arc welding which needs striking a low-voltage, high current arc between the electrode and the specimen or base metals. Welding is no longer a new field in industry. It is familiar amongst industrial
sector which give the income opportunity ad very crucial to industry. Minnick (1988) stated that welding is defined as a jumping procedure by heating them to the welding temperature, with or without the application of pressure alone, and with or without the use of filler metal that produces coalescence of materials.

Brittle materials had mechanical limitation of flexural strength which defined as the ability of the material to resist bend under load which will be measured in terms of stress, \( \sigma \). Before experiencing failure, the materials mostly will fail under tensile stress. Thus, the maximum tensile stress value that can be obtained before the failure is known as flexural strength. Therefore, the correlation between the welding and flexural strength is to be determine by changing the thickness and joint design of specimen.

Flexural strength is the limit for material without failure to withstand flexural stress under load. It also known as modulus of ruptures or bend strength is a mechanical parameter for brittle material and it known as a material's ability to withstand deformation under load. Nowadays demand for high quality and reliable components and materials are increasing so flexural tests have become vital test method in both the research and manufacturing process and development to explain in details about the material’s ability to withstand deformation under load.

Recently, there are lack research study on the effect of thickness, welding type and joint design on the flexural condition. This is because the flexural condition or strength of material on certain loads with different and weld type application is very important to manufacturing industry so that it is able to resist deformation under load. According to Dowling (1999), within the elastic range, brittle materials show a linear relationship of load and deflection where yielding occurs on a thin layer of the specimen surface at the midspan. This in turn leads to crack initiation which finally proceeds to specimen failure.

Junior (2015) reported that flexural strength is the limit for material without failure to withstand flexural stress under load. If the material has low flexural strength, the failure occurrence will be higher. It is important that a material to have flexural strength in order to avoid any failure or fatigue and increase product life cycle. Therefore, this research was come out with the analysis study on the flexural strength of mild steel since it is not well documented. In this experiment, the researchers were successfully study and identify which factors have the great impact to flexural strength.

1.1 Design of Experiments (DOE).

R. A. Fisher in England in the 1920’s introduced a very powerful statistical technique on Design of Experiments (DOE). In Fisher’s early applications, he wanted to investigate and find out how much water, fertilizer, rain, sunshine and the other ‘ingredients’ are needed in order to produce the best corp. Henceforth, the technique has been developed for academic applications. Additionally, the techniques did help a lot in many applications especially in the production floor of industrial sector. At present, Design of Experiments (DOE) has become one of the dominant and powerful tools used to reveal deeply the hidden causes of process variation. These DOE techniques are very useful for surfacing the effect of hidden variables during process design and development stage. Experimental techniques range from randomly introduced uncontrollable factor to carefully controlled factors (Xu, 2008).

DOE (Design of Experiments) provides a powerful means to achieve breakthrough improvements in product quality and process efficiency. From the viewpoint of manufacturing fields, this can reduce the number of required experiments when taking into account the numerous factors affecting experimental results. Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output. DOE can show how to carry out the fewest number of experiments while maintaining the most important information.

1.1.1. Basic Principles of Doe. There are three basic principles of experimental design, which are randomization, blocking and replication:
1.1.1.1 Randomization. In a good experiment design, the treatments have to be assigned to the experimental units in such a way that no treatment is consistently favoured by being placed under the best conditions. The process of randomization can do this. The reasons for randomization in an experimental design are to eliminate bias and ensure independence among the observations. Randomization ensures that no treatment is favoured or discriminated against by systematic assignment of units in a design.

1.1.1.2 Blocking. Blocking is associated with the need to perform experiments in groups of runs. Suppose the raw material for the system comes from a batch process. If it is suspected that, all other factors being the same, different batches will lead to different levels of the experiment’s responses, and then blocking would be appropriate.

1.1.1.3 Replication. The replication means a repetition of the basic experiment. Replication helps to obtain an estimate of the experiment error. This estimation of error becomes a basic unit of measurement for determining whether observed differences in the data are really statistically different. If the sample mean is used to estimate the effect of a factor in the experiment, then replication helps to obtain a more precise estimate of this effect (Ranjan, 2001).

2. Experimental

The experiment must be done carefully to get the best data before proceed to analyse it. Before conducting the experiment, a brainstorming had been performed as an integral part in designing the best and effective experiments. It was used to determine the parameters, response and strategy involved in the experiment. At the same time, it ensures that the experiment achieves the objectives. It means, to conduct a successful experiment, an appropriate and correct strategy needed. The $2^3$ design of experiment was conducted because the three factors have contribution to the result of flexural strength value. The $2^3$ factorial design that is, a design with three factors each two level which can be define as low level and high level. The experiment done with two replications which means 16 runs of the experiment.

2.1 Parameter Selection.

The experiment designed were set which each factor run at two levels; high level (1) and low level (-1). The analysis and model fitting for 2k factorial design in this study using coded design variables 1 and -1, and not the design factors in the original unit. Coded variables are very effective for determining the relative size of factor effects. Table 1 shows the parameter settings:

| Table-1: Parameter Settings for Experiment |
|------------------------------------------|
| Term | Factor     | Low Level | High Level |
|      |            | Un-coded  | Coded      | Un-coded | Coded |
| A    | Welding Type | SMAW      | -1         | GMAW     | 1     |
| B    | Thickness (mm) | 6         | -1         | 4        | 1     |
| C    | Joint Design | Lap Joint | -1         | Butt Joint | 1     |
The total numbers of treatment combination are 16. All of the setting runs with randomization. Randomization is the design technique used to guard against such a lurking nuisance factor. The nuisance factor must be avoid or eliminate to ensure it’s not contribute to the experiment. By referring the results for pilot run recorded in Table 2, it is clearly shown that the highest flexural strength value is 2764 N/mm² at the combination of GMAW welding, 4mm thickness and Lap joint. The highest flexural value is the better.

Table-2: Pilot Run for Experiments

| Std Order | Run Order | A       | B       | C       | Flexural Strength (N/mm²) | Log₁₀ Flexural Strength (N/mm²) |
|-----------|-----------|---------|---------|---------|--------------------------|---------------------------------|
| 13        | 1         | SMAW    | 6       | Butt    | 997.98                   | 3.0                             |
| 12        | 2         | GMAW    | 4       | Lap     | 2764.66                  | 3.4                             |
| 16        | 3         | GMAW    | 4       | Butt    | 991.37                   | 3.0                             |
| 8         | 4         | GMAW    | 4       | Butt    | 1015.28                  | 3.0                             |
| 10        | 5         | GMAW    | 6       | Lap     | 2633.26                  | 3.4                             |
| 15        | 6         | SMAW    | 4       | Butt    | 784.65                   | 2.9                             |
| 1         | 7         | SMAW    | 6       | Lap     | 2437.47                  | 3.4                             |
| 6         | 8         | GMAW    | 6       | Butt    | 846.39                   | 2.9                             |
| 11        | 9         | SMAW    | 4       | Lap     | 2468.49                  | 3.4                             |
| 5         | 10        | SMAW    | 6       | Butt    | 840.27                   | 2.9                             |
| 7         | 11        | SMAW    | 4       | Butt    | 893.27                   | 3.0                             |
| 3         | 12        | SMAW    | 4       | Lap     | 2394.13                  | 3.4                             |
| 9         | 13        | SMAW    | 6       | Lap     | 2538.16                  | 3.4                             |
| 2         | 14        | GMAW    | 6       | Lap     | 2252.09                  | 3.4                             |
| 14        | 15        | GMAW    | 6       | Butt    | 923.69                   | 3.0                             |
| 4         | 16        | GMAW    | 4       | Lap     | 2629.67                  | 3.4                             |

3. Results.

3.1. Normality Test.
Normality test are conducted for a set of data to ensure that the sample of data taken represent the population of data. From the result gain, the normality test was carried out using Ryan-Joiner Test and show that the P-value is below than 0.05 so that the data need to be transform by Log₁₀ the data. After transformation, P-value is >0.10 which is greater than 0.05. Thus, the data is normal since there is no significance different between the actual data with the ideal data. Figure 1.0 show the normal probability plot for flexural strength.
3.2. Two Replication of the $2^3$ Design.

The experiments conducted using two replications per run. The number of replicates that the experimenter can employ may be restricted. The total experiment will be run for 16 trials. Figure 2 show the normal probability plot for effect estimates. Based on Figure 2, factors that represent, normal probability with black dots which fall on the line or along the line are not significant and can be negligible, whilst the red coloured square which diverted away from the line is the significant factor for the experiment. The red coloured square is factor C which is joint design.

3.3. Analysis Of Variance (ANOVA).

The significant factor which has been identified earlier using normal probability plot for effect estimates can be verified using ANOVA. Result of the ANOVA above in Table 3 shows that joint design has the highest value of $P$ which is 0.000 which is most significant because it value is below than 0.05. For the 2-way interaction, the $P$-value is greater than 0.05 but it can be considering have the interaction between welding type vs thickness because it $P$-value is 0.0625 which is nearest to 0.05.
Table-3. Table of ANOVA

| Source                            | DF | Seq SS | Adj SS | Adj MS | F     |
|-----------------------------------|----|--------|--------|--------|-------|
| Main Effects                      | 3  | 0.746476 | 0.746476 | 0.252158 | 384.33 |
| welding type                      | 1  | 0.000425 | 0.000425 | 0.000425 | 0.13  |
| thickness                         | 1  | 0.000923 | 0.000923 | 0.000923 | 0.33  |
| joint design                      | 1  | 0.756425 | 0.756425 | 0.756425 | 405.33 |
| 2-Way Interactions                | 3  | 0.001875 | 0.001875 | 0.001875 | 0.33  |
| welding type*thickness            | 1  | 0.000425 | 0.000425 | 0.000425 | 0.13  |
| thickness*joint design            | 1  | 0.000923 | 0.000923 | 0.000923 | 0.33  |
| 3-Way Interactions                | 1  | 0.000625 | 0.000625 | 0.000625 | 0.33  |
| welding type*thickness*joint design| 1  | 0.000425 | 0.000425 | 0.000425 | 0.13  |
| Residual Error                    | 8  | 0.015000 | 0.015000 | 0.001875 |       |
| Total                             | 15 | 0.752475 |        |        |       |

3.4. Main Effect Plot and Interaction Plot

Main effects plot is used to determine which level (1 / -1) of the factor will affect the response output and to compare the relative strength of the effects. The main effects of Welding Type and Thickness are positive and Joint Design is negative. If consider only those main effects, the optimal setting will be high level for Welding Type and Thickness and low level for Joint Design to maximize the value of flexural strength. The main effect of factor Welding Type is GMAW (+), Thickness is 4mm (+) and Joint Design is Lap Joint (-). Figure 3 show the main effect plot for each individual’s factors.

![Main Effect Plot for Broken Nuts](image-url)
However, from the table ANOVA indicates that there is one interaction is significant, it is always necessary to examine any interactions that are important. Remember that main effects are meaningless when they are involved in significant interactions. Figure 4 show the interaction plot for the flexural strength. Figure 4 above show the interaction plot for flexural strength. Referring to welding type and thickness interaction, the highest flexural strength achieved when welding type is at GMAW (+) and thickness is at 4mm (+). For welding type and joint design interaction, the highest flexural strength achieved when welding type is at GMAW (+) and Joint Design at Lap Joint (-). Analysis study for thickness and joint design interaction shown that the highest flexural strength achieved when thickness is at 4mm (+) for lap joint (-) condition. Therefore, the best parameters setting to achieved highest flexural strength would appear to be obtained for GMAW welding type for 4mm thickness A36 Mild Steel with lap Joint design.

4. Conclusion.
A full factorial with two replication experiments used in this study successfully identifies the significant parameters and optimal setting. The optimal settings are recommended as GMAW welding, low thickness (4mm) and Lap joint. The highest flexural strength value is record at 2764 N/mm². For welding condition of GMAW with 4mm thicknesses of sample in lap joint design condition. The highest flexural value is the better.

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