Failure Analysis of A Welded Mild Steel Shaft Under Tensile Loading Condition

Arshad Hussain (arshad15me04@gmail.com)  
Indus University  https://orcid.org/0000-0003-4277-9385

Fida Hussain
Mehran University of Engineering & Technology

Abdul Sattar
Quaid-e-Awam University of Engineering Science and Technology

Tanweer Hussain
Mehran University of Engineering & Technology

Qadir Bakhsh
Quaid-e-Awam University of Engineering Science and Technology

Muhammad Ahmed
MH Engineering

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Abstract

Welding is a process of permanently joining two or more parts by the application of heat and (or) pressure and is the widely used process in fabrication, maintenance and repairs of parts and structures. Almost 70 percent of all manufactured products are made with the skills of welders. In the field of Mechanical Engineering the modern welding trends and advanced products are made with the skills of welders. In the field of Mechanical Engineering the modern welding trends and advanced welding process has been contributing toward advancement, a study has been given greater priority of failures analysis of welding joints and various structural and technical aspects have an impact on fracture characteristics of welded joints. The welded joints and various structural aspects have an impact on fracture characteristics of welded joints. The objectives of this work were to investigate the tensile behavior of welded mild steel shaft to analyzing the failure analysis of welded joints for that purpose step joint, lap joint, double v joint, double v pin joint and double j joint specimens of standard size were developed. Each specimen was machined, welded and finished at its center. A tensile test was performed on all the welded shaft of mild steel. Tensile test has been carried out by Universal Testing Machine, after testing the specimens, it was found that the welded shaft with Lap Joints bears the Maximum Tensile Strength.

Introduction

Welding is a method that uses heat and (or) pressure to permanently connect two or more components. It is commonly used in the manufacturing, maintenance, and repair of parts and structures. A welded joint must be designed to resist the forces that it will be subjected to during the span of its service life. Excessive tension can be maintained by some welded joints. The study of failure analysis of welded joints, as well as the influence of numerous structural and technological parameters on fracture properties, has gained increasing importance during the last few years. Weak designs, inaccurate dimensioning, residual stresses in joints, or metallurgical changes in the base material will reduce shaft life and may finally result in catastrophic failures resulting in severe injuries or death. The strength of the welded joint depends on various parameters like welding speed, welding current welding geometry, etc.

The tensile strength of welded joints is increased with the increase in current. The value of hardness varies with distance from the welded center. Weld strength is more on low welding speed due to more intensity of current [1–4]. Current and speed are the important parameters affecting output responses. Selection of proper joint and preparation of welding geometry greatly affect welding strength and preparation of welding joint. Welding defects can be optimized by these proper welding precautions: Current grain, size, Speed, Axis, etc. [5–9]. Talabi, S.l.et.al [10] the impact of welding factors on mechanical qualities was discussed. The welding parameters that were investigated were welding current, arc voltage, welding speed, and electrode diameter. Increases in arc voltage and welding current resulted in enhanced hardness but decreased yield strength, tensile strength, and impact toughness, according to the research. Radha Raman Mishra [11] determined the tensile strength of MIG and TIG welded dissimilar joints of mild steel and stainless steel. A Universal Testing Machine with a capacity of 400 KN was used for tensile testing. The TIG welding technique is more durable. It could be because TIG
welding produces less porosity in dissimilar metal welds, and the amount of carbon precipitation produced by welding is likewise lower.

WoongJo Choi et.al [12] In friction stir welding, the effects of welding settings and backing plate diffusivity on energy consumption were determined. The plates were extruded in the direction of the welds. The ultimate tensile strength decreases with an increase in welding current but increases at the welding current of 200A and 115A for mild steel and low carbon steel respectively. It becomes a necessity to apply heat treatment to the weldment and the parent metal after conducting a welding operation. Heat treatment softens the metal, changes the grain size, modifies the material’s structure, and relieves the stresses that have built up in the material [13–15]. The high volume of the weld metal widens the weld and hence the HAZ, increasing the risk of weld faults [16]. As compared to Ti/SS joints or IL, the tensile strength of the welds was substantially improved when using Ni interlayer [17–19] F. Muhammad. et.al [20] The Effect of Post-Weld Heat Treatment on Mechanical and Electrochemical Properties of Gas Metal Arc-Welded Stainless Steel was investigated, and it was discovered that the microstructures of AISI 316L as-welded regions consist of austenite grains and carbides as black dots, but that after PWHT, grain refinement occurred, resulting in improved mechanical properties.

**Materials**

Mild steel is a type of carbon steel with a low amount of carbon. The Mild Steel specimens of standard size were taken as the base material for welding. MS rods are easily available and commonly used materials for welding and fabrication in industry. The parent metal (MS rods) possesses a tensile strength of 670 MPA, a Maximum load of 152.25 KN, and elongation of 17.85. The novelty of this work is that in this research work total of six types of welding specimens have been taken and the comparison of their results with tensile loading conditions has been presented. No any work has been presented for comparison of these 6 groups of specimens for failure analysis in the condition of tensile loading conditions.

**Methodology**

MS Rods of 1-inch diameter and length of 18 inches was taken and cut into specimens of two equal lengths of i.e. 9 inches and equal diameter of 1 inch Total thirty-six specimens were taken. The length and diameter of each specimen were the same whereas the geometry of joints was different. The specimens were divided into six groups (S.J, D.V.J, L.J, D.V.P.J, D.J.J, and O.S). These groups were subdivided into two groups (A & B) having three specimens in each subgroup.

Specimens with different geometric shapes were formed at Machine Shop (Workshop) at Quaid e Awam University of Engineering Science & Technology Nawabshah by performing different operations on Lathe Machine.

**3.1 Geometric Shapes Formed**
For the Tensile test of the welding joint, some specimens were taken. The process of taking specimens repeated for every type of joint Like as Step-Joint, Double-V-Joint, Double V-Pin Joint, Double J-Pin Joint, and Lap Joint.

During welding 05mm space was kept between two specimens after which the specimens formed were of 18.2inches long.

The angle of tapering was 23.4 and could be calculated by using the following formula:

\[
\frac{D-d \times 144}{L} = 5
\]

After performing the taper turning process specimens were welded through electric arc welding in the welding shop.

double V shapes were formed on the shafts by using the taper turning process in which larger diameter “D” was 25.4mm and smaller diameter “d” was 09.4mm and on other shafts, double V shapes were formed by using the taper turning process in which larger diameter “D” was 25.4mm and smaller diameter “d” was 09.4mm and after that these shafts were drilled with 9.4mm drill bit.

Double V shapes were formed on the shafts by using taper turning process in which larger diameter “D” was 25.4mm and smaller diameter “d” was 09.4mm and the other side is drilled 05mm by drill bit of 09.4mm.

After reducing its half diameter from one side up to 20mm of length, specimens were welded through electric arc welding in the welding shop. During welding 05mm space was kept between two specimens after which the specimens formed were 18.2inches long.

3.2 Manufacturing Operations Performed during Formation of Specimens

3.2.1 Cutting

The purchased pieces were 18 inches long and of 01-inch diameter. These pieces were cut into 09 inches’ pieces by using a power hack saw in the Machine Shop of QUEST Nawabshah.

3.2.2 Facing

Facing is performed on all the specimens. Only 0.1mm material is removed from both the ends of all specimens so that all the blurs are removed from the faces to ensure the safety of operators.

3.2.3 Taper Turning

Taper turning operation was performed to decrease the diameter of the specimen at any angle (i.e. 23.04 in double v-joint, double j-pin joint, or Double V-pin joint).
3.2.4 Drilling

Drilling was performed to make a new hole in the specimen by using a drill bit of different diameters according to the demand of the required hole. Drilling was performed in a double v-joint and taper pin joint to make the hole of 9.4mm of the specimens.

3.2.5 Turning

The turning operation was performed to reduce the diameter and to make a gauge length on the work specimens.

3.2.6 Welding

Welding operation was performed to joint together two specimens of 09-inch length. After the machining, all groups of specimens were weld by shielded metal arc welding using Electrodes of Zodian Universal Brand. The welding current was kept at 160A. The electrode material used is E6013 with a 0.10 mm diameter. E6013 is a high titanic coated MS electrode with a tensile strength of 450 MPA. All the welding work is done in the welding shop of QUEST Nawabshah.

Those welded specimens were not as per the standards of the tensile testing machines. So, for making standard specimens turning was performed on all the welded specimens to set a gauge length on which the behavior of the MS shafts could be investigated.

3.3 Testing of Specimens

A tensile test is perhaps the most basic type of mechanical test you can do on material for investigating failures in welded joints of shafts. Tensile strength is the main characteristic evaluation considered in the present study to identify the effects of welding. The tensile test is performed on an E-Series Hydraulic Servo Computer Control Universal Testing Machine (Fig. 10). MaxTest.exe program is installed on the PC to control the machine. The load of the machine is in the range of 50kN to 2000kN. Readings and graphs were taken for all the groups and then these results were compared to give conclusions.

Results

A tensile test was performed on different groups of welded specimens. Tensile Test was performed on Manual Universal Testing Machine UMH-100 present in Material Testing Laboratory QIEST Nawabshah, Workshop. Load of the machine is in the range of 50kN to 2000kNLoad was given and the test was performed on each specimen and Stress-Strain graphs were taken. The specimen was first fixed in the machine jaws and then the tensile load was applied to it.

4.1 Original Specimen

Group OS, (non-welded specimen group) was tested so that we may compare the results of the non-welded specimens with the results of welded specimens. Its properties and stress-strain graph is given
Table 1
Property of Specimens of O.S Group

| Specimen Group | Ultimate Tensile Load (MN) | Ultimate Tensile Stress (MPA) | Fracture Point Load (MN) | Fracture Point Stress (MPA) |
|----------------|-----------------------------|-----------------------------|--------------------------|---------------------------|
| O.S-1          | 211                         | 67                          | 156                      | 89                        |
| O.S-2          | 210                         | 67                          | 164                      | 87                        |
| O.S-3          | 225                         | 69                          | 129                      | 103                       |
| O.S (mean)     | 215                         | 68                          | 168                      | 93                        |

4.2 Step Joint

Group S.J (welded specimen group) was tested so that we may compare the results of the welded specimens with the results of non-welded specimens. Tensile test was performed on specimens group S.J. There were 03 specimens in group S.J welded using Zodian Universal brand electrode. The properties and graphs of this group of specimens are shown below:

Table 2: Properties of Specimens of Group S.J

| Specimen group name | Ultimate Tensile Load (MN) | Ultimate Tensile Stress (MPA) | Fracture Point Load (MN) | Fracture Point Stress (MPA) |
|---------------------|-----------------------------|-----------------------------|--------------------------|---------------------------|
| S.J- 1              | 117                         | 37                          | 104                      | 37                        |
| S.J- 2              | 124                         | 40                          | 97                       | 42                        |
| S.J- 3              | 117                         | 37                          | 105                      | 41                        |
| O.S (mean)          | 119                         | 38                          | 102                      | 40                        |

4.3 Double V- Joint

Group D.V.J, (welded specimen group) was tested so that we may compare the results of the welded specimens with the results of non-welded specimens. Tensile test was performed on specimens group D.V.J. There were 03 specimens in group D.V.J welded using Zodian Universal brand electrode. The properties and graphs of this group of specimens are shown below. Below are the graphs of the specimen group D.V.J. These graphs are taken from the tensile testing machine. Further, the properties of this specimen group are shown in Table 03.
Table 03
Properties of Specimens of Group D.V.J

| Specimen group name | Ultimate Tensile Load (MN) | Ultimate Tensile Stress (MPA) | Fracture Point Load (MN) | Fracture Point Stress (MPA) |
|---------------------|---------------------------|------------------------------|--------------------------|-----------------------------|
| D.V.J -1            | 130                       | 33                           | 111                      | 45                          |
| D.V.J -2            | 88                        | 28                           | 57                       | 27                          |
| D.V.J -3            | 130                       | 15                           | 111                      | 43                          |
| D.V.J (mean)        | 116                       | 34                           | 99                       | 38                          |

4.3 Double V- Pin Joint

Group D.V.P.J, (welded specimen group) was tested so that we may compare the results of the welded specimens with the results of non-welded specimens. Tensile test was performed on specimens group D.V.P.J. There were 03 specimens in group D.V.P.J welded using Zodian Universal brand electrode. The properties and graphs of this group of specimens are shown below:

Above are the graphs of the specimen group D.V.P.J. These graphs are taken from the tensile testing machine. Further, the properties of this specimen group are shown in the table below.

Table 04
Properties of Specimen Group D.V.P.J

| Specimen group name | Ultimate Tensile Load (MN) | Ultimate Tensile Stress (MPA) | Fracture Point Load (MN) | Fracture Point Stress (MPA) |
|---------------------|---------------------------|------------------------------|--------------------------|-----------------------------|
| D.V.P.J -1          | 74                        | 23                           | 62                       | 21                          |
| D.V.P.J -2          | 111                       | 35                           | 77                       | 30                          |
| D.V.P.J -3          | 129                       | 41                           | 104                      | 39                          |
| D.V.P.J (mean)      | 104                       | 33                           | 81                       | 30                          |

4.4 Double J- Pin Joint

Group D.J.P.J, (welded specimen group) was tested so that we may compare the results of the welded specimens with the results of non-welded specimens. Tensile test was performed on specimens group D.J.P.J. There were 03 specimens in group D.J.P.J welded using Zodian Universal brand electrode. The properties and graphs of this group of specimens are shown below:
Above are the graphs of the specimen group D.J.P.J. These graphs are taken from the tensile testing machine. Further, the properties of this specimen group are shown in the table below.

Table 05
Properties of Specimens of Group D.J.P.J

| Specimen group name | Ultimate Tensile Load (KN) | Ultimate Tensile Stress (MPA) | Fracture Point Load (MN) | Fracture Point Stress (MPA) |
|---------------------|-----------------------------|-------------------------------|--------------------------|-----------------------------|
| D.J.P.J -1          | 61                          | 22                            | 56                       | 17                          |
| D.J.P.J -2          | 54                          | 17                            | 41                       | 14                          |
| D.J.P.J -3          | 104                         | 33                            | 85                       | 30                          |
| D.J.P.J (mean)      | 73                          | 24                            | 60                       | 20                          |

4.5 Lap joint

Group L.J, (welded specimen group) was tested so that we may compare the results of the welded specimens with the results of non-welded specimens. Tensile test was performed on specimens group L.J. There were 03 specimens in group L.J welded using Zodian Universal brand electrode. The properties and graphs of this group of specimens are shown below:

Above are the graphs of the specimen group L.J. These graphs are taken from the tensile testing machine. Further, the properties of this specimen group are shown in the table below:

Table 06
Properties of Specimen of Group L.J

| Specimen group name | Ultimate Tensile Load (MN) | Ultimate Tensile Stress (MPA) | Fracture Point Load (MN) | Fracture Point Stress (MPA) |
|---------------------|-----------------------------|-------------------------------|--------------------------|-----------------------------|
| L.J -1              | 88                          | 28                            | 75                       | 24                          |
| L.J -2              | 106                         | 51                            | 80                       | 58                          |
| L.J -3              | 78                          | 24                            | 57                       | 25                          |
| L.J (mean)          | 90                          | 34                            | 71                       | 36                          |

Conclusion

The principal objective of this work is to investigate the failure analysis of the welding shaft under the tensile behavior of load. For that purpose several types of specimens like Step Joint, Lap Joint, Double V Joint, Double V Pin Joint, and Single J Joint and to suggest the best type of Joint. All the groups of
specimens were first machined on Lathe Machines available at QUEST, Nawabshah workshop. After finishing of specimen tensile was performed on all the specimens. The finding of this work is as follows:

- After testing all the specimens, it was concluded that the Welded Shafts with Lap Joint bears the Maximum Tensile Strength. So, Lap Joint was found strongest and is greatly recommended in case the shafts are subjected to Tensile Load.
- It was also observed from fractured specimens during the application of load that the selection of a proper type of joint and preparation of proper welding geometry greatly affect welding strength and preparation of welding joint.

Declarations

Availability of data and materials:

Full Data of this study is included in this manuscript and also available to corresponding author.

Competing Interest:

The authors declare no competing financial interests

Funding:

Not Applicable

Author's Contribution:

Abdul Sattar and Qadir Bakhsh were supervised during whole experimental work at Quaid e Awam University of Engineering Science & Technology Nawabshah, Arshad Hussain & Fida Hussain worked for material and manufacturing process selection. Tanweer Hussain give the valuable suggestion for Journal selection and manuscript Setup. Muhammad Ahmed work for data saving and tables setup. All authors read and approved the final manuscript.

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References

1. Ma, Y., Takikawa, A., Nakanishi, J., Doira, K., Shimizu, T., Lu, Y., & Ma, N. (2021). Measurement of local material properties and failure analysis of resistance spot welds of advanced high-strength steel sheets. Materials & Design, 201, 109505.
2. Bhat, S. D., Vijeesh, V., Acharya, P., & Rao, M. (2021). Investigation of thin sheet stainless steel resistance spot welds: Effect of weld current on nugget failure and microstructure. Materials Today: Proceedings, 35, 361-365.

3. Rao, S. S., Chhibber, R., Arora, K. S., & Shome, M. (2017). Resistance spot welding of galvannealed high strength interstitial free steel. Journal of Materials Processing Technology, 246, 252-261.

4. Wei, Y., Luo, Y., Qu, H., Zou, J., & Liang, S. (2017). Microstructure evolution and failure analysis of an aluminum–copper cathode conductive head produced by explosive welding. Journal of Materials Engineering and Performance, 26(12), 6158-6166.

5. Shuaib, N. A., Osman, M. S., Subri, A. S. M., Nadzri, M. L. M., Bakri, N. I. M., Shahrin, A. S., & Firdaus, N. S. (2021, May). Assessing risks and control measures on a welding workshop in Malaysia. In AIP Conference Proceedings (Vol. 2339, No. 1, p. 020218). AIP Publishing LLC.

6. Wanjari, M. B., & Wankhede, P. (2020). Occupational Hazards Associated with Welding Work That Influence Health Status of Welders. Int J Cur Res Rev| Vol, 12(23), 51.

7. Abbas, E. N., Omran, S., Alali, M., Abass, M. H., & Abood, A. N. (2018, October). Dissimilar welding of AISI 309 stainless steel to AISI 1020 carbon steel using arc stud welding. In 2018 International Conference on Advanced Science and Engineering (ICOASE) (pp. 462-467). IEEE.

8. Rout, A., Deepak, B. B. V. L., & Biswal, B. B. (2019). Advances in weld seam tracking techniques for robotic welding: A review. Robotics and computer-integrated manufacturing, 56, 12-37.

9. Antonia, O. SAFETY ISSUES IN THE SCULPTURE STUDIO EVEN IN THE NEW NORMAL.

10. Talabi, S. I. A., Owolabi, O. B. B., Adebisi, J. A. A., & Yahaya, T. A. (2014). Effect of welding variables on mechanical properties of low carbon steel welded joint. Advances in Production Engineering & Management, 9(4), 181-186.

11. Radha Raman Mishra, Visnu Kumar Tiwari and Rajesha S (April 2014) a study of tensile strength of mig and tig welded dissimilar joints of mild steel and stainless steel, International Journal of Advances in Materials Science and Engineering ,3(2), 23-32

12. Choi, W. J., Morrow, J. D., Pfefferkorn, F. E., & Zinn, M. R. (2017). The effects of welding parameters and backing plate diffusivity on energy consumption in friction stir welding. Procedia Manufacturing, 10, 382-391.

13. Kosturek, R., Śnieżek, L., Wachowski, M., & Torzewski, J. (2019). The influence of post-weld heat treatment on the microstructure and fatigue properties of Sc-modified AA2519 friction stir-welded joint. Materials, 12(4), 583.

14. Baghdadi, A. H., Rajabi, A., Selamat, N. F. M., Sajuri, Z., & Omar, M. Z. (2019). Effect of post-weld heat treatment on the mechanical behavior and dislocation density of friction stir welded Al6061. Materials Science and Engineering: A, 754, 728-734

15. Cheepu, M., Venkateswarlu, D., Mahapatra, M. M., & Che, W. S. (2017). Influence of heat treatment conditions of Al-Cu aluminum alloy on mechanical properties of the friction stir welded joints. 264-264.
16. Kar, P., Behera, J., Pradhan, J., Bhujabal, S., Sarkar, S., & Naik, B. Parametric Optimization and Taguchi Application of bead geometry and HAZ width in submerged arc welding using a mixture of fresh flux and fused flux.

17. Hosseini, S. R. E., Feng, K., Nie, P., Zhang, K., Huang, J., Li, Z., ... & Xue, S. (2019). Interlayer thickening for development of laser-welded Ti-SS joint strength. Optics & Laser Technology, 112, 379-394.

18. Zhang, Y., Chen, Y., Zhou, J., Sun, D., & Gu, X. (2020). Forming mechanism and mechanical property of pulsed laser welded Ti alloy and stainless steel joint using copper as interlayer. Journal of Materials Research and Technology, 9(2), 1425-1433.

19. Negemiya, A. A., Rajakumar, S., & Balasubramanian, V. (2019). High-temperature diffusion bonding of austenitic stainless steel to titanium dissimilar joints. Materials Research Express, 6(6), 066572.

20. F.Muhammad, A.Ahmad, A.Farooq & W.Haider, Effect of Post-Weld Heat Treatment on Mechanical and Electrochemical Properties of Gas Metal Arc-Welded 316L (X2CrNiMo 17-13-2).

**Figures**

![Figure 1](image-url)

Figure 1

Specimen for Tensile Test
Figure 2

Machine Shop of QUEST Nawabshah
Figure 3

Specimens of Step Joint after Machining
Figure 4

Specimens of Double V-Joint after Machining

Figure 5

Specimens of Double V-Pin Joint after Machining
Figure 6

Specimens of Double J-Pin Joint after Machining

Figure 7

Specimens of Lap Joint after Machining
Figure 8

Welded Specimens
Figure 9

Finished Specimens
Figure 10

Universal Testing Machine

Figure 11

Stress-strain graph of O.S-1  Stress-strain graph of O.S-2  Stress-strain graph of O.S-3
Stress-Strain Diagram of Original Specimens

Figure 12
Stress-Strain Graph of Group S.J

Figure 13
Stress-Strain Graph of Group D.V.J
Figure 14

Stress-Strain Diagram of D.V.P.J

Figure 15

Stress-Strain Diagram of Group D.J.P.J
Figure 16

Stress-Strain Diagram of Group L.J