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# EFFECT OF WELDING PARAMETERS ON JOINT PERFORMANCE OF FRICTION WELDED A106 PIPES

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**ABSTRACT :**
This study was performed to explore the influence of spindle rotation time and upsetting pressure as process parameter on the mechanical properties of the welded joints produced from friction welding. Experiments were performed considering the Taguchi design resulting in joints with excellent bead formation, reinforcement height. After visual inspection the samples were tested for the highest tensile strength which was found to be 350.80 MPa along with hardness value of 156.67 HV achieved at a spindle rotation time of 30 seconds and at an upsetting pressure of 6 MPa. The contour plot indicated slight improvement in the mechanical properties when the spindle rotation time and pressure is maximum which was acknowledge by regression analysis but the S/N ratio showed no significant effect. Overall, this study highlights that spindle rotation time and upsetting pressure plays crucial role for obtaining a good weld quality and mechanical properties.
**Keywords**: Friction welding, A106, spindle speed, spindle rotation time, upsetting pressure.

## INTRODUCTION:
Friction welding is being increasingly acknowledged as an alternative to traditional fusion welding, like SMAW and GMAW, for joining pipelines and components. These long-established welding methods are optimized for productivity; however, they offer limitations. High-energy beam systems have been utilized to enhance productivity; friction welding has its own set of advantages whereby it uses frictional heat to join any material without actually melting it, thus putting it in a class of solid-state welding techniques. This allows uniform heating and joining combinations of materials such as pearlitic steels, stainless steels, and nonferrous metals. This welding process, by the application of compressive forces, achieves coalescence, thereby accomplishing strong ductile joints requiring no further thermal treatment.

Extensive research has been performed to explore various aspects of friction welding in regard to joining pipes and cylindrical components. These researches highlight the important process parameters, mechanical performance, microstructural evolution, and technological advances in friction welding.

To understand the fundamental mechanics of the friction welding technique, a simulation method was developed based on the material properties and the welding conditions to estimate the initial frictional torque requirement [1]. Welding was performed on steel pipes with inner diameter as 8mm and outer diameter as 13.5mm. To enhance the joint strength and to reduce flash generation an optimized study was carried out on the groove shape formation. It was observed that joints with slight tapered groove shape exhibited the desired output [2]. During welding of stainless-steel tubes with high thickness, parameters considered were rotational speed, applied force, welding time and material upset. The optimization of the process parameters concluded that the higher forging force positively influenced the tensile strength of the joint; with the material upset playing a crucial role in ensuring a leak-proof welded joint [3]. The welding of aluminum AA6061-T6 pipes with thickness of 3mm, using Taguchi L25 orthogonal array design for carrying out experiments. The optimized parameters considered were burn-off length, frictional and upset force, spindle speed, and upsetting time, which produced weld with strength approximately to that of base material. ANOVA was employed to obtain the significance of each of the parameters [4]. During welding of dissimilar pipe components of stainless-steel material, thermochemical behaviour was studied using finite element model through analysing the temperature distribution and material flow was studied using a high-speed camera, demonstrating that the optimal heat distribution was essential in providing joint integrity and longer heating time increases the joint interface temperature [5].

Friction welding between ASTM A106 and AISI 4140 steel pipes was performed using different conditions. It was evident that during the welding of low-alloy steel AISI 4140 pipes, the increase in upsetting pressure caused the micro-hardness to increase while lowering the impact strength due to the formation of carbides at the weld joint. These welded joints were heat treated post welding which drastically modified the microstructural features by forming recrystallized microstructures with different hardness levels influencing the joint strength and toughness [6,7]. Similarly, for understanding the effect of various inputs, a study was conducted to explore the factors such surface geometry, presence of scale, clamping, duration of heating, forging etc. It was concluded that to achieve high-quality welds, there is a necessity to clean surfaces and remove scales as this severely compromises the ductility and impact toughness of the weld, although the welding strength is maintained [8].

For welding long pipelines in the industry, a unique friction welding process was developed, which produced joints of thick-walled pipes effectively, eliminating the requirement of cleaning the surface [9]. Friction welding is rising in prominence because it is an economical and efficient means of joining similar and dissimilar metals, especially in the aerospace and automotive industries, where it is largely the only option for materials with widely varying physical properties [10]. A different study also explores rotating arc-welding, too identified as magnetically impelled arc butt (MIAB) welding, a technique for circumferential pipe welding. The method uses an electromagnetically driven arc that rotates rapidly, safeguarding even heat distribution for effective joining of pipes[11].

Thus, this process is widely used in the industries owing to low welding times, less tooling cost, and the ability to weld similar & dissimilar materials. It also solves bonding problems with low-melting-point materials, extending its application into both structural and non-structural domains. The technique works very well for the joining of pipes, thereby enhancing its use in oil, gas, and petrochemical industries.

## MATERIALS AND METHODS:

The material used is ASTM A106 Grade B steel pipes with outside diameter of 48.1mm and a thickness of 5.08mm. The chemical composition of the material is given below in Table 1.

**Table 1:** Chemical composition (wt. %) of ASTM A106 Grade B Steel

| Material | C | Mn | S | P | Si | Cr | Ni | Mo | V | Cu |
|---|---|---|---|---|---|---|---|---|---|---|
| ASTM A106 Grade B | 0.21 | 0.60 | 0.01 | 0.015 | 0.27 | 0.057 | 0.014 | 0.007 | 0.001 | 0.017 |

Experiments were carried out on a modified lathe machine which has a hydraulic system assembled in the tailstock. This hydraulic power pack is used for applying both frictional as well as the upsetting pressure. The welding was performed at a spindle speed of 980 rpm, considering other parameters as upsetting pressure ranging between 4MPa to 6MPa and Spindle rotation times ranging from 20s to 30s. After a series of trials, the optimum value of initial frictional pressure was taken as 1MPa which was suitable for current thickness and diameter. This value may vary depending on the outer diameter as well as the thickness of the pipe and also depends on the material used. Experiments were done by considering L9 Taguchi orthogonal array design of experiments. After successfully carrying out the experiments the pipes were visually inspected and then they were tested for their mechanical properties by extracting the specimens. The extraction of specimen was done using wire-cut Electric Discharge Machining (EDM) in accordance with ASTM E8/E8M-08 represented in Figure1. These specimens were tested for their tensile strength on UTM and hardness using Vickers hardness tester utilizing a diamond-type indenter.

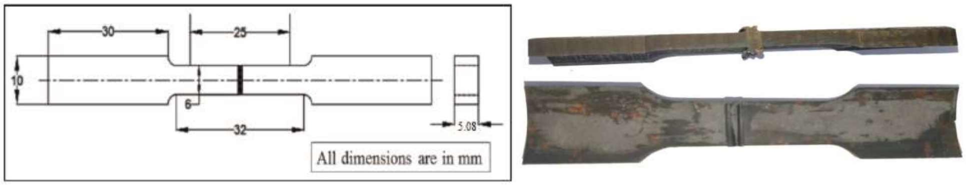


**Fig. 1:** Schematic diagram of Tensile Test specimen and extracted specimen

**RESULTS AND DISCUSSION:**

The resulting joints showed differences in reinforcement height, heat-affected zone (HAZ) width, and bead formation. Each combination of pressure and time duration produced a uniform bead. A visual inspection confirmed that the weldments were properly reinforced, sound, and free from any visible defects. The maximum tensile strength of 350.80MPa and hardness value of 156.67 HV was achieved with the selected parameters. The contour plots as shown in Figure 2. represent the relationship between the Spindle rotation time (20-30 sec), and upsetting pressure (4-6 MPa) and the resulting mechanical properties of the welded samples. The plot represents with increase in spindle rotation time and upsetting pressure there is a slight increase in both ultimate tensile strength and hardness.

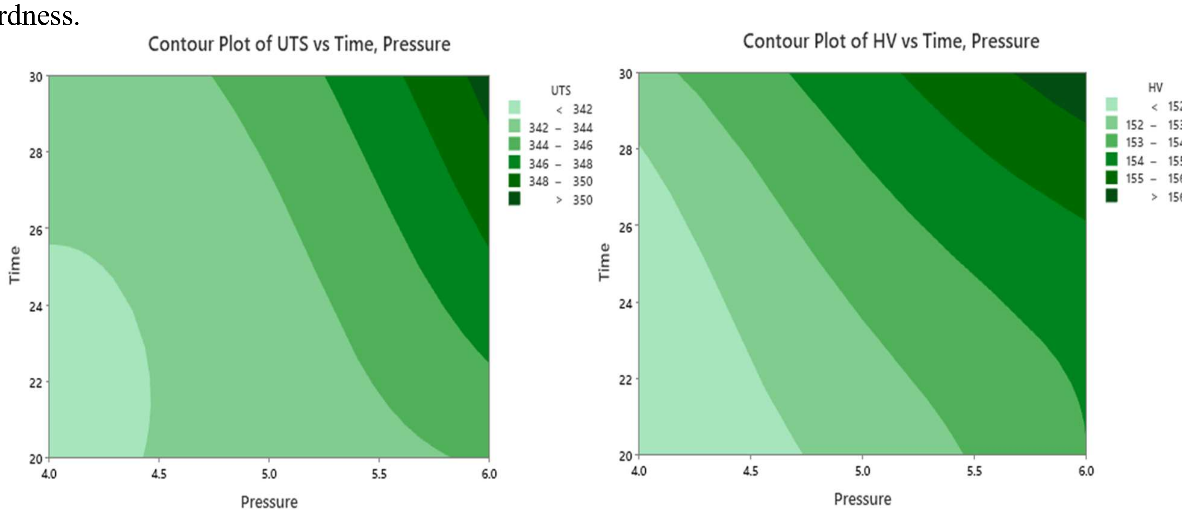


**Fig. 2:** Contour Plot of Ultimate Tensile Strength & Hardness vs Time, Pressure

The figure 3. presents the S/N ratio analysis of tensile strength & Hardness, showing that while tensile strength increases with variations in spindle rotation time and upsetting pressure, the change is not highly significant. The highest tensile strength & Hardness (S/N) ratio, following the larger-the-better principle, was achieved at the combined settings of A3 and B3—specifically, a spindle rotation time of 30 seconds and an upsetting pressure of 6 MPa.

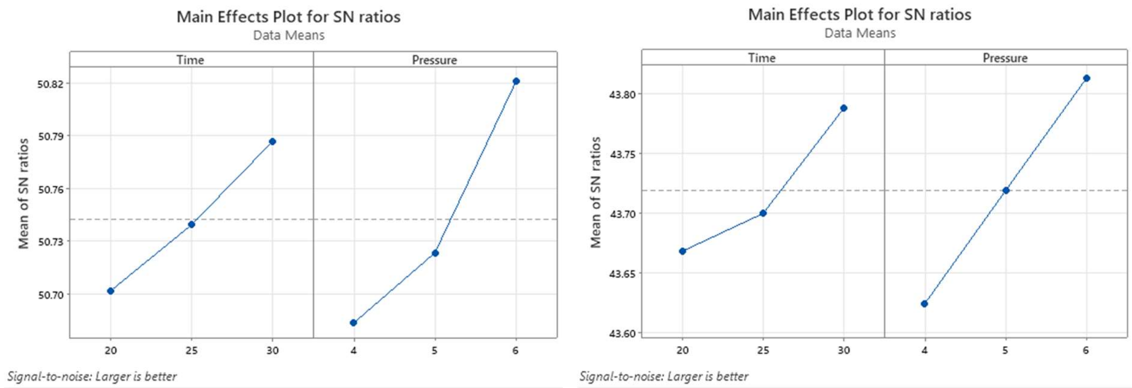


**Fig. 3:** Main Effects Plot for S/N ratio for Tensile Strength & Hardness

The regression analysis of tensile strength (UTS) and hardness (HV) highlights the significant impact of upsetting pressure and spindle rotation time. For tensile strength, an increase in pressure raises UTS by 2.740 units per unit increase and for hardness by 1.668 units per unit increase, while rotation time also plays a crucial role, especially at longer durations. The model accounts for a substantial portion of the variance, with both pressure and time making significant contributions, as confirmed by the ANOVA results as shown in table 2.

**Table 2: Regression Equation for Tensile Strength & Hardness**

| Time | | Time | |
|---|---|---|---|
| 20 | UTS = 329.13 + 2.740 Pressure | 20 | HV = 144.212 + 1.668 Pressure |
| 25 | UTS = 330.63 + 2.740 Pressure | 25 | HV = 144.768 + 1.668 Pressure |
| 30 | UTS = 332.52 + 2.740 Pressure | 30 | HV = 146.328 + 1.668 Pressure |

The below probability plots illustrate the distribution of tensile strength and hardness values along with their associated probabilities. Since each value has an equal probability, the distribution is uniform, meaning all values are equally likely to occur. Figure. 4 show that tensile strength and hardness values are spread across the range of pressure values. The uniform distribution suggests that there is no specific trend or bias toward particular tensile strength or hardness values within the dataset. Overall, the plot effectively represents the probability distribution in a clear and visually appealing manner, highlighting the consistency of the dataset.

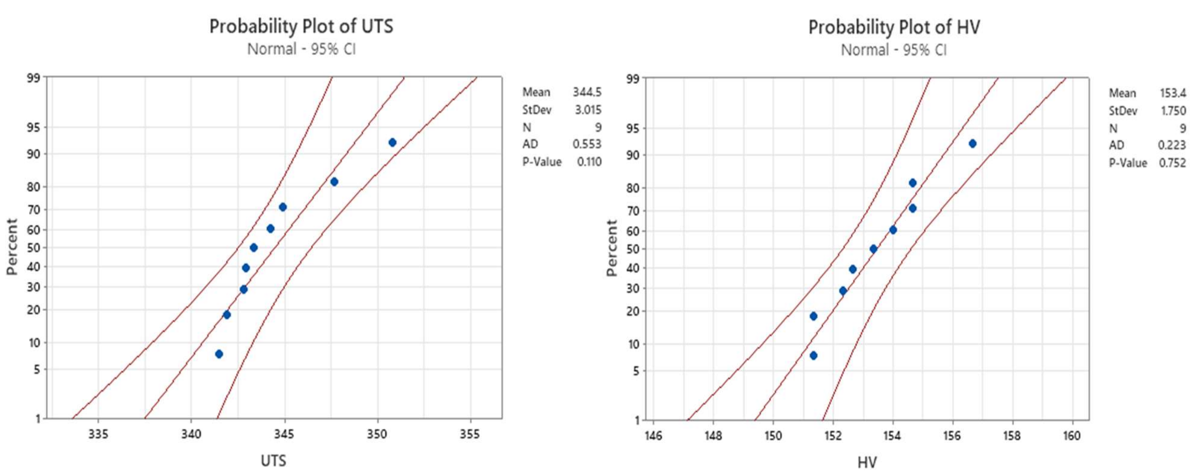


**Fig. 4:** Probability Plot of Tensile Strength & Hardness

**CONCLUSION:**

The welded joints obtained exhibited variations in bead formation, heat-affected zone (HAZ) and also in the reinforcement height. However, the visual inspection confirmed that all the weldments were sound and properly reinforced without defect. The highest tensile strength of 350.80 MPa and the hardness of 156.67 HV were achieved at a spindle rotation time of 30 seconds and at an upsetting pressure of 6 MPa. This combination provided the most favorable mechanical properties. Thus, it can be concluded that the spindle rotation time and upsetting pressure significantly affects the mechanical properties of the welded joint. These optimal parameter values can be used to achieve superior weld quality with enhanced tensile strength and hardness.

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