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INFLUENCE OF FRICTION PRESSURE ON MECHANICAL PROPERTIES OF FRICTION WELDED DISSIMILAR JOINTS

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ABSTRACT :
Friction welding (FW) is a solid-state joining process that utilizes mechanical friction to generate heat and produce a bond between two materials. In this study, the effect of variable friction and forge pressure on the hardness, tensile strength, and elongation of dissimilar steel joints between ASTM 106 Grade B steel and EN 19 steel was investigated. The primary objective was to understand the influence of frictional heat and forge pressure variations on the mechanical properties of the welds, which are critical for their performance in industrial applications. The welding process was performed under varying friction pressures ranging from 1.5, 2 MPa and forge pressures ranging from 5 MPa. After welding, the joints were characterized using hardness testing, tensile testing, elongation measurement and EDX spectra. The hardness of the weld zone was observed to increase with higher friction pressure due to more localized heat generation, resulting in stronger bonding between the two steels. Similarly, tensile strength decreased at higher frictional settings. The results indicated that a balance between friction and forge pressures is essential for achieving an optimal combination of hardness, tensile strength, and elongation. The study provides valuable insights into the behavior of dissimilar steel joints in friction welding, offering guidance for optimizing welding parameters to achieve superior joint performance in applications requiring high strength and reliability.
Keywords: Friction welding, Vickers hardness, tensile strength, Percentage elongation

INTRODUCTION:

Friction welding works by rotating one of the components (typically the "rotating" workpiece) against the other (the "stationary" workpiece). The heat generated due to the friction between the materials causes them to soften locally at the interface. The components are then brought together under pressure, and the material at the interface undergoes plastic deformation, resulting in a solid-state bond. ASTM 106 Grade B Steel is a carbon steel primarily used for high-temperature applications. It is known for its strength, corrosion resistance, and ability to withstand pressure. It is commonly used in the construction of pipes, boilers, and other high-pressure components. EN 19 Steel is a high-strength alloy steel that contains chromium and nickel. It is known for its good tensile strength, impact resistance, and ability to be heat treated. It is commonly used in applications such as shafts, gears, and structural components that require high strength and toughness. Friction welding is commonly used to join dissimilar materials, like S. Senthil Murugan et. al [1] electroplated SS304L alloy rods were friction welded with AA6063 at varied upset pressures (UP) (18, 21, and 24 MPa). The findings of the produced dissimilar joints' weld microstructures, fracture pictures, energy-dispersive X-ray spectroscopy, tensile properties, joint efficiency, Vickers micro-hardness, and Charpy V- notch test. MuralimohanCheepu&P. Susila [2] have investigated friction weld Ti to stainless steel. To further understand the metallurgical interactions between the substrates and interlayer, the thermal characteristics of the weld interface were measured. Jeswin Alphy James and Sudhish R. [3] have examined the influence of a nickel interlayer on the microstructure and mechanical properties of dissimilar friction welds between AISI 1040 and SS304 stainless steel materials. The Ultimate tensile strength of welds without using interlayer was 636 Mpa at highest forging pressure of 1.884 ton. Micro hardness results showed a decrease in peak hardness at the interface (391 Hv) which was 454 Hv when welded without using interlayer which is due to the reduction in the precipitation of chromium carbide at the interface due to presence of nickel. Suresh D. et.al [4] have developed friction welding technique for joining aluminium (AA6061) to low alloy steel (AISI 4340) using an interlayer of silver. Silver as an interlayer, resulting in better tensile strength and ductility of welds. MuralimohanCheepu et. al [5] have studied a unique approach of electro deposited nickel coating on one of the substrates (stainless steel) as an interlayer was used to successfully fuse dissimilar joints of titanium and stainless steel. Optical microscopy, scanning electron microscopy, and energy dispersive spectroscopy were used to examine the bonding interface of the joints. The nickel interlayer junctions had a greater tensile strength than the direct joints. Microstructural analysis of the titanium–stainless steel interface revealed the lack of brittle Fe–Ti intermetallic complexes, which was attributable to the employment of the interlayer method. The existence of Ti–Ni phases, which were more plastic than Fe–Ti intermetallic compounds, was recognized as the characterization of the interface. MuralimohanCheepu et.al& Woo Seong Che [6] have investigated to improve the mechanical properties of the joints made by friction welding of stainless steel to titanium with aluminium insert metal. Muralimohan CH.et.al [7] have investigated the parameters affecting the friction welding joint between pure titanium to a 304L stainless steel with an electroplated nickel interlayer. Metallographic analysis revealed that a good bonding was obtained at both the titanium/nickel and nickel/stainless steel interfaces, and the diffusion products were identified in the weld zone. Ateekh Ur Rehman et. al [8] have studied Solid-state dissimilar friction welds of Inconel 718 and F22 were prepared with an Inconel 625 interlayer to address the carbon enrichment of Inconel 718 during the welding. Amit Handa and Vikas Chawla [9] have conducted experimental studies on friction welded joint of low-alloy steel (AISI 1021) with the austenitic stainless steel (AISI 304) at 1250 rpm under different axial pressures (ranging from 75 to135 MPa) and the mechanical properties such as tensile strength, impact strength and hardness were experimentally determined. S. D Meshram et. al [10] In this study, dissimilar metal combinations Fe–Ti, Cu–Ti, Fe–Cu, Fe–Ni, and Cu–Ni were studied since Fe, Cu, Ti, and Ni are the most widely utilised alloyed materials in engineering applications. Ihsan Kirik [11] have investigated friction weld dissimilar metals, such as Ti6Al4V to duplex stainless steel, with and without a nickel interlayer. The weld was metallographically examined, and the strength of the joints was assessed using tensile testing. MuralimohanCheepu et. al [12] Friction welding was used to weld the dissimilar junction of austenitic stainless steel to high tensile alloy steel. Interface microstructure, axial shortening, joint temperature, micro hardness, and tensile strength have examined at the weld interface. At an interface, the thickness of the intermixing zone was determined, as well as its fluctuation with welding conditions. The influence of the intermixing zone in dissimilar welds on mechanical characteristics was examined. The tensile strength of the welds is related to the thickness of the intermixing zone. The intermixing zone and dynamically re- crystallized zone had the maximum hardness, according to the micro-hardness profiles.

EXPERIMENTAL SET UP:

Friction welding machine

A continuous drive linear friction welding machine of the YUAN YU make of model YU-60 was used for friction welding in the present investigation. The input parameters considered are friction pressures 1.5, 2 MPa, forge pressures ranging from 5 MPa, Friction time is 30 secs and forge time is 10 secs. The friction welded joints of parent materials are shown in the figure 1.

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Figure 1: Friction welded joints of parent metals

PARENT MATERIALS:

A variable diameter of commercially available low alloy steel EN 19 seamless pipe of 14.5 mm diameter and 7.1 mm thickness ASTM 106 grade B steel was used in the present investigation. The chemical composition and the mechanical properties of the selected steel are given in Tables 1 and 2 respectively.

Table 1: Chemical composition (wt %) of ASTM 106 Grade B and EN 19

Materials	C	Mn	S	P	Si	Cr	Mo	Ni	Vn	Cu
ASTM106 Grade B	0.21	0.60	0.01	0.015	0.27	0.057	0.014	0.007	0.001	0.017
EN 19 steel	0.44	0.77	0.016	0.015	0.24	1.040	0.0009	0.187	0.019	0.015

Table 2: Mechanical properties of ASTM 106 grade B steel and EN 19 steel

S.No.	Property	ASTM 106 Grade B	EN 19 steel
1	Yield Strength (MPa)	303.6	415
2	Tensile Strength (MPa)	428.42	655
3	Elongation (%)	32.2	25.7
4	Hardness (Hv)	160	197

RESULTS AND DISCUSSIONS:

Hardness:

Hardness is measured using Vickers Hardness tester by an indenter (as a diamond point) that penetrates microscopic areas.The values of Vickers hardness at variable friction pressure are tabulated below in the table 3

Table 3: Vickers hardness values at variable friction pressure

	Vickers hardness of EN 19 (Hv)	Vickers hardness of ASTM 106 grade B steel (Hv)	Vickers hardness HAZ 1 at EN 19 side (Hv)	Vickers hardness HAZ 1 at ASTM 106 grade B side19 side (Hv)	Vickers at weld interface
Friction pressure 1.5 Mpa	110	310	119	298.77	287

Friction pressure 2 Mpa	114	339	120	321	295.33

ASTM 106 Grade B is a low-carbon steel (0.26%–0.30% carbon content). This steel is generally used in high-temperature applications (e.g., boilers, pipes). It has moderate strength and hardness. EN 19 steel is a high-strength, low-alloy steel that contains chromium and nickel, which gives it higher hardness and strength compared to ASTM 106. When high friction pressure is applied during welding, it generates more heat at the interface, which increases the plastic deformation of the material. This can cause the formation of a softer, heat-affected zone (HAZ) at the interface due to the material's low carbon content. The resultant heat reduces the hardness of the welded region. Lower friction pressures may not generate enough heat, leading to a less effective weld and potentially higher hardness in the HAZ due to insufficient softening of the steel. However, this can also lead to poor bond formation.The initial pressure applied during the friction phase plays a crucial role in controlling the heat generated and the material flow. In figure 2 variable friction pressure can be applied to optimize the heat generation and material mixing. A higher friction pressure will lead to more localized heating and a stronger bond, while lower friction pressure may result in insufficient heat generation and a weak joint.

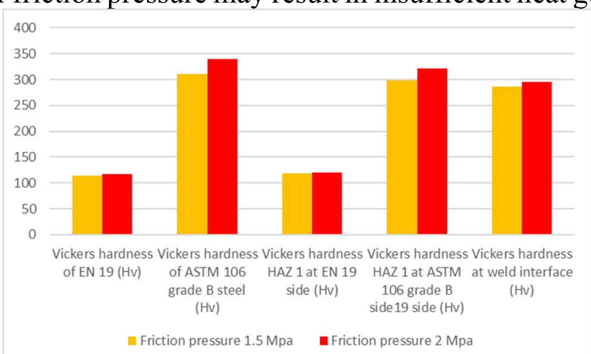

Figure 2: Vickers hardness at variable friction pressure

TENSILE STRENGTH

Higher friction pressures can lead to more significant material deformation at the interface, improving the interfacial bond strength by promoting better mixing and plastic flow of the material. This can enhance the tensile strength of the welded joint because a stronger bond forms between the two materials. However, if the friction pressure is too high, it can lead to excessive material extrusion or even burn-through, leading to weak or flawed joints. If the friction pressure is too low, the materials may not generate enough heat to adequately soften the interface, resulting in a weak bond. This can lead to a lower tensile strength of the joint, as the interface may not be properly forged. Friction pressure directly influences the heat generation. Adequate heat is necessary for proper material flow, while excessive heat can lead to issues such as grain growth, which reduces tensile strength. The relationship between friction pressure and heat must be optimized for both ASTM A106 and EN 19. Both ASTM A106 and EN 19 undergo phase transformations when heated. In the case of EN 19, higher pressures could lead to the formation of martensite or bainite in the weld zone, affecting the tensile strength. In contrast, ASTM A106 may exhibit reduced strength in the weld zone if not carefully controlled, especially at high temperatures. The values of tensile strength and % elongation are tabulated below in table 4

Table 4: Tensile strength and % elongation values at different levels of friction pressure

	Ultimate tensile strength (MPa)	% elongation
Friction pressure 1.5 Mpa	330.22	50
Friction pressure 2 Mpa	294.54	46.58

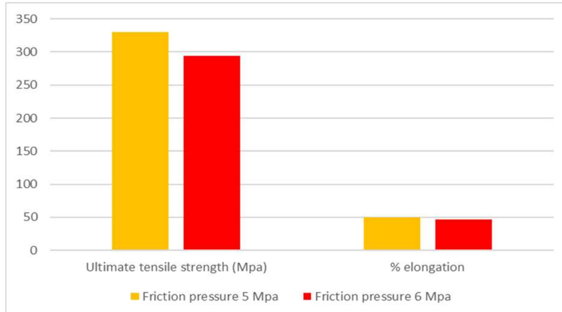

Figure 3: Tensile strength and % elongation values at different levels of friction pressure

From figure 3 it is evident that as friction pressure increases, the frictional heat generated at the interface between the two materials increases. This higher temperature can lead to changes in the material properties, such as softening of the steel, which reduces its tensile strength. The increased temperature may cause excessive grain growth, leading to a decrease in strength. Higher friction pressure can result in more deformation of the material, potentially leading to the formation of defects such as voids, cracks, or an irregular bonding surface. These defects can act as stress concentrators and reduce the overall tensile strength of the joint.

ENERGY DISPERSIVE X RAY ANALYSIS (EDXA) :

Friction welding involves the application of pressure and rotational motion, leading to heat generation at the interface of the two materials being welded. The friction pressure influences the temperature, the amount of deformation, and the phase changes in the material at the weld interface. These factors can impact the distribution of elements in the weld zone, thus altering the EDX spectra. Increased pressure during the welding process may cause more deformation of the materials, leading to a finer microstructure at the weld interface. This can result in a more homogeneous distribution of elements. Elements like carbon, manganese, sulphur, and phosphorus in ASTM A106 Grade B and EN 19 steel might be more uniformly mixed at higher pressure levels. At lower pressures, less deformation occurs, and the materials may remain less mixed. This could result in an uneven distribution of elements at the weld interface, leading to detectable composition differences in the EDX spectra. More elemental segregation might occur in this case. At high Pressure Diffusion rates are typically enhanced, allowing for a more uniform distribution of elements like carbon and alloying elements (e.g., chromium in EN 19). This could lead to a more blended spectrum with subtle gradients in the elemental composition across the weld interface. At low Pressure diffusion is reduced, so the EDX spectra may show more distinct differences between the two materials at the interface, with limited mixing of alloying elements. The friction pressure can influence the formation of intermetallic phases, which could significantly affect the EDX spectra. At higher friction pressures, the localized heat and pressure could lead to the formation of intermetallic compounds, which may be rich in elements like iron, chromium, nickel, or carbon, especially in steels like EN 19. At high friction Pressure, formation of intermetallic phases can lead to strong peaks in the EDX spectra for specific elements. The interface may show enriched areas in certain elements, which can appear as distinct peaks in the EDX spectrum. With lower friction pressure, the formation of intermetallic phases may be minimized, resulting in a less complex EDX spectrum, with fewer peaks associated with the formation of such phases.To describe the solid-state diffusion of carbon, manganese, and chromium silicon atoms across the weld joint of C, Mn at the weld interface, elemental spectroscopy was performed on the friction-welded EN 19 steel and ASTM A 106 Grade B steel pipes near the weld interface region. The figure 4 shows the EDX spectra at 1.5 MPa friction pressure. The figure 5 shows the formation of intermetallic as friction pressure increases. The occurrence of intermetallic phases at the weld interface may result from the

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presence of nickel, chromium, and other alloying components. This might have an impact on the joint's overall performance. These stages are frequently fragile and, if not adequately managed, might weaken the weld.

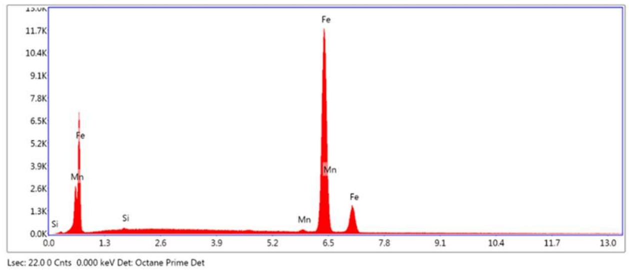

Figure 4: EDX spectra at 1.5 MPa friction pressure

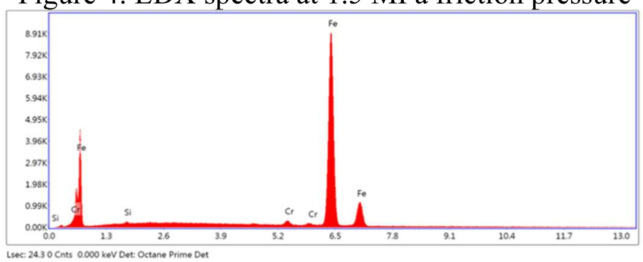

Figure 5: EDX spectra at 2 MPa friction pressure

CONCLUSIONS:

In friction welding of ASTM 106 Grade B steel and EN 19 steel at varying friction pressures, the hardness difference plays a crucial role in determining the quality of the weld. At lower pressures (1.5 MPa), the bond may be weaker due to insufficient plastic deformation, especially on the harder EN 19 steel. At higher pressures (2 MPa), the process becomes more effective, improving the bond strength by allowing more plastic deformation and better mixing of the materials. The balance between the hardness of the materials and the applied friction pressure is critical in obtaining a strong, durable joint. The decrease in tensile strength with higher friction pressure is likely due to the combination of thermal effects (overheating), material degradation, and changes in the microstructure of the materials involved. Balancing the friction pressure and heat generation is crucial for ensuring a strong bond without compromising the material properties.

With the increase in friction pressure there is a formation of intermetallics at the weld interface which makes the joint weak and brittle.

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