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REVIEW ON FRICTION STIR WELDING OF CARBON STEEL

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Abstract

Carbon steel was a commonly used material in petrochemical and oil and gas plants all over the world. Most of the pressure vessels, heat exchangers, boilers, fin fan coolers, piping, etc. were made from different grades of carbon steel. In order to proceed with welding, use Gas tungsten arc welding (GTAW) or Shielded metal arc welding (SMAW) for lesser thickness and Flux cored arc welding (FCAW) or Submerged-arc welding (SAW) for higher thickness. FSW was not a regularly utilized welding technique in the chemical and oil and gas industries, but it has seen enormous achievement in the welding of aluminum, copper, magnesium, and other lighter materials. FSW has several uses in sectors such as the aircraft, railway, shipbuilding, and automobile industries. FSW joints outperform the base material in terms of mechanical qualities. Because of the added benefit of minimal heat input, FSW is an appealing solution for connecting diverse materials. This results in less distortion, less defective, residual stress, and good corrosion properties. This research presents background on the friction stir welding process used for similar and dissimilar carbon steel, including different grades of carbon, and classifies major process parameters (rotation speed, welding speed, and tool material) that affect the weld's mechanical and metallurgical properties. It also utilizes inspection methods (destructive and nondestructive) to confirm the assessment of a sound weld.

Keywords: Friction Stir Welding, Carbon Steel.

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I. Introduction

Friction stir welding (FSW) was invented by TWI for the first time in 1991[1]. Since then, it has been extensively researched for materials with low melting points, primarily Al, Mg, and Cu alloys. [2-4] .since there is no external heat source used during base metal (BS) welding, the material's properties are not significantly changed. This feature sometimes elevated the joint characteristics above BS. [5] The welding heat is produced by friction between the tool's contact area and the BS. [6-7] In this case, the base metal experiences thermo-mechanical deformation due to the rotation of the FSW tool within the BS. (TMD). The formation of fine and equiaxed re-crystallized microstructures in the joint line during TMD enhances the final properties of welded samples. [8–13] The FSW process has a number of advantages, such as low heat input, little to no filler material, no fume, and no welding spatter. Additionally, there is very little pre-processing done before joining, less post-joining stress, and fewer porosities and cracks. [14] Important process characteristics include the tool rpm, shoulder diameter, and travel speed. The early research on the FSW technique (illustrated in figure.1) was restricted to alloys made of aluminum and magnesium due to their lower melting points. The research is currently being extended to high temperature materials like carbon steel, stainless steel, alloy steel, etc., though, as numerous experts have noted [15-20]

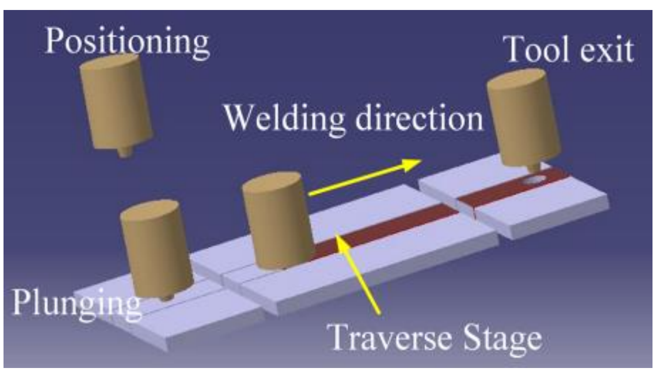

Fig. 1. FSW process [53]

II. Literature review

There are three main types of carbon steel, each with a different amount of carbon: interstitial steel, low carbon steel, and medium carbon steel (IF steel, S12C, and S35C). To examine the impact of the carbon content in these steels, Hidetoshi Fujii et al. employed FSW. The test plate's dimensions were 300mm long, 30mm wide, and 1.6mm thick. The rotational speed and welding speed are shown in Table 1. With the help of optical microscope (OM) observations and electron backscattering pattern (EBSP) technology, the mechanical and microstructural features of each FSW joint were evaluated. Using a cross-section perpendicular to the welding direction, the Vickers hardness and tensile strength of each joint were evaluated. While the low carbon steel joints' strengths rose as welding speed increased, those of medium carbon steel joints reached a peak at about 200 mm/min (decreasing the heat input). [21]

An FSW was performed by Ling Cui and colleagues on a high-carbon steel joint (S70C -0.72 wt.% C) without the material being preheated or post heated in any way. Table 1 displays both the welding speed and the rotational speed for your reference. During the welding process, he made the discovery that the variations in composition as well as the temperature cycle had a significant influence on the development of the microstructure and, therefore, the mechanical properties of high-carbon steels. Friction stir welding allows us to adjust these parameters and make strong welds, even in high-carbon steels, without having to resort to preheating or post heating. [22]

Ling Cui et al. friction stir welded five different carbon steels, including IF steel, S12C, S20C, S35C, and S50C, under varied welding settings in order to evaluate the mechanical and microstructural features. It will be inferred that the strength of the FSW joints for all carbon steels examined in this study increased above that of the typical structure for the base metal. (Ferrite pearlite). In comparison to IF steel, the welding conditions have a substantial effect on the microstructures and mechanical properties of carbon steel joints. As welding speed increases, peak temperature lowers and cooling rate increases. These values are not affected by the steel type. [23]

This investigation details the effects of employing 12% chromium alloy steel as well as plain, low-carbon steel and a number of different permutations of 12% chromium steel and carbon steel. Tensile and bending tests show that the mechanical properties of joints made by friction stir welding a 12% chromium alloy to low-carbon steel are on par with those of the parent metal. [24]

When it comes to welding high-carbon steels, friction stir welding has the potential to eliminate the need for post-weld heat treatment altogether. This set of practical guidelines shows maps of peak temperatures and cooling rates for different types of friction stir welding with high-carbon steel. Even though it has been said that both the peak temperature and the rate at which it cools can be controlled, these maps are still being given. [25]

T. J. Lienert et.al demonstrated that an AISI 1018 mild steel plate FSW may be manufactured with a thickness of 6.3 millimeters. Using thermocouples and an infrared camera system, it was possible to determine that the peak surface temperatures reached 1,000 degrees Celsius (1832 degrees Fahrenheit) on both the workpiece and the tool while the welding operation was being carried out. The tool was subjected to both rubbing wear and tool deformation, as determined by metallographic and metrological measurements obtained of the tool before and after welding. This resulted in changes in the dimensions of the tool.. [26]

FSW was successful in producing a defect-free weld in ultrahigh carbon steel (containing 1-2 weight percent carbon) by utilizing a polycrystalline cubic boron nitride (PCBN) tool. This steel had a duplex structure consisting of ferrite and cementite. We took a close look at the weld's hardness profile and microstructure, as well as how the microstructure changed as the friction stir welding technique progressed. Near the middle of the weld, the duplex structure composed of ferrite and cementite was transformed by FSW into a martensitic structure. [27]

In the current investigation, hyper-eutectoid steel (0.85 mass percent C, AISI-1080) is welded using friction stir welding at a maximum temperature lower than A1 in order to exclude martensite transformation as a possibility during the joining process. (726 C). It is feasible to successfully fuse materials without the formation of martensite structure, and the resulting junction has an impressively high level of toughness. This shows that it is possible to weld high-carbon steel sheets using the FSW method, which should considerably contribute to lowering the amount of carbon discharge produced by the manufacturing sector. [28]

Both without and with a gas torch, FSW was able to successfully weld the SK5 (0.84 wt% C) that Don-Hyun Choi et.al provided. There were no defects seen in the weld zones. All of the specimens broke in the base metal, which demonstrates that FSW welding is reliable regardless of whether or not a gas torch is present. The tensile strengths of both occurrences were equivalent to those of the base metal. [29]

Lakshminarayanan et al. conducted research on the microstructural changes, tensile and impact toughness parameters, and fracture site of friction stir-welded AISI 1018 mild steel.. Also, it was found that the tensile strength and hardness of the stir zone were 8% greater than those of the base metal. This was attributed to the production of microscopic, equiaxed ferrite and pearlite grains in that region. [30]

FSW was performed on hot-rolled DH36 carbon steel that was 6.4 mm thick at varied rotational and transverse speeds. Based on the data on weld nugget hardness, overmatching went up as cooling rates went up, and specific weld energy went down as welding speed went up. [31]

Shabbir Memon et al. studied UFSW on low carbon steel. 60 4-mm A441 AISI steel pieces were welded for FSW and UFSW. . FSWED cases generated more heat (1228 °C) than UFSWED joints (1008 °C). . FSWed and UFSWed joint line radiography showed no abnormalities. The underwater stir zone grain size was lowered by the joint line's rapid cooling rate, according to welded sample microstructure studies. According to the evaluation tensile strength of the welded samples, the underwater connector had 13.5 percent greater ultimate tensile strength than the normal FSW joint. [32]

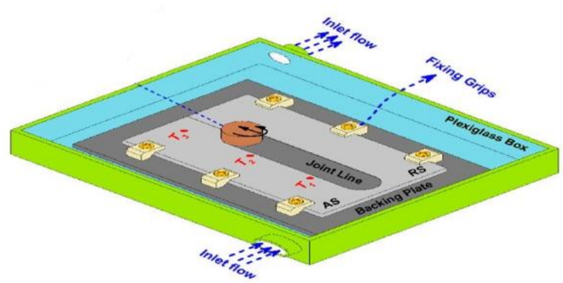

Fig.2 Graphic view of underwater friction stir welding [32]

In a study by Jafarzadegan et al., plates of stainless steel 304 and st37 steel were connected by FSW at tool rotational speeds of 600 rpm and 50 mm/min, respectively. According to the findings, the stir zone (SZ) of 304 stainless steel showed a better microstructure and some indicators of metadynamic recrystallization.. Despite the fact that the weld's strength and ductility were higher than those of st37 steel BM, st37 steel was formed as a result of the transverse tensile specimens breaking. [33]

R. Ueji butt-welded in the rolling direction using an FSW with three different low-carbon steel sample types (quenched, cold-rolled, and annealed sheets). (RD). FSW can successfully join all varieties of quenched, cold-rolled, and annealed steel. The cold-rolled steel joint with the highest minimum hardness has the slowest rotational speed. (250 rpm). The martensitic site procedure and FSW are combined to make a steel joint with a good strength balance between the stir zone and the base metal while maintaining a high strength, which involves (steps 1) quenching, (steps 2) cold rolling, (steps 3) FSW, and (steps 4) subsequent annealing. This mixture is depicted in Figure 3. [34]

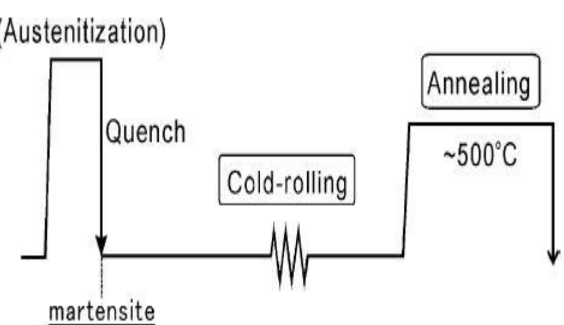

Fig. 3. Heat treatment in the FSW process [34]

A 5 mm-thick chunk of FSWed mild steel LR-FH32 that would be used to construct ships was examined by

Mohamed et al. for its microstructure and mechanical characteristics.. The presence of fine-grained ferrite and bainite (acicular ferrite) with an average grain size of 3 mm in the low-welding-speed (20 mm/min) joint demonstrates that the temperature was significantly higher than A1, the temperature at which ferrite and austenite combine, and that the austenite transformed into bainite when it cooled.. [35]

Fujii et al. looked at how carbon content and transformation affect the mechanical properties and microstructures of different types of carbon steel joints, such as interstitial steel, low carbon steel, and medium carbon steel (IF steel, S12C, and S35C). We can make stronger connections by controlling the maximum temperature and rate of cooling during friction stir welding. [36]

Bhatia et al. (AISI 1018) increased the ultimate tensile strength of friction stir-welded carbon steel. The parametric research for output responses was created using response surface methods, and the adequacy of the model was assessed using an analysis of variance (ANOVA).It was found that the speed of welding and the RPM of the tool have a big effect on the ultimate tensile strength.[37]

The effects of pin rotation speed and welding speed on the mechanical behavior and microstructure development of mild steel (ST-37) produced by friction stir welding (FSW) were examined by Saman et al. [38].

TABLE I
LOW CARBON STEEL PARAMETERS

Work piece	Thk (mm)	Rotation Speed (RPM)	Welding speed (mm/min)	Tool	Ref
Mild Steel Low CS	6.35	450-650	25-100	MW alloys	[26]
AISI 1018	5	1000	50	WC alloys	[30]
DH 36 Low CS	6.4	204-456	200	WC alloys	[31]
A441 Low CS	4	900	60	WC	[32]
Low CS	2.3	250-1000	100	WC	[34]
Mild steel Low CS	5	500	20-50	WC	[35]
ST 37 Low CS	2	450-560	50-160	WC	[38]
AISI 1018 Low CS	3	750	60	WC-Co	[46]
SS 400 Low CS	3.2	400-800	50-300	WC	[47]
SS 400 Low CS	40	150	25	PCBN	[48]
A 516 Low CS –A 625	6	300	100	PCBN	[50]
Low CS	4	800-1400	50	WC	[53]
Low CS	4	600	132	WC-Co	[63]
Q235 MS	3	475	47.5	WC-Co	[66]
SAE J412 Low CS	2	800-1400	84-104	WC	[67]
St 52	4	630	65	WC	[69]

Wang et al. investigated the microstructure and mechanical properties of worn mild steel using friction stir welding (FSW), which allows for welding at lower temperatures. FSW was utilized to mix the two different chemically constituted weathering steels, SMA490-AW and SPA-H, below the A1 temperature. The microstructure of the welded joints and the micro-hardness for each individual weld zone were examined using a scanning electron microscope (SEM) and electron backscatter diffraction (EBSD). The dynamic qualities were then evaluated using digital image correlation (DIC). [39]

Medium-carbon steel was friction stir welded while being rapidly chilled with liquid CO_2 below the A1 transition temperature. Because of its rapid thermal breakdown, liquid CO_2 cooling during friction stir welding provides a higher degree of coarsening. The arrangement of microscopic cementite nanoparticles among tiny ferrite grains increases the mechanical characteristics of the joint. [40]

In this study, two different types of metal, Type 304 stainless steel (SS304) and Q235 low carbon steel (FSW), were joined together using friction stir welding. The joint's microstructure, interface characteristics, residue stress concentration, and mechanical properties were all investigated. FSW induces grain refinement in the thermal-mechanically affected zone on the stainless steel 304 side and in the fusion zone, according to the results. [41]

TABLE II
MEDIUM CARBON STEEL PARAMETERS

Work piece	Thk (mm)	Rotation Speed (RPM)	welding speed (mm/min)	Tool	Ref
Med CS	2	100	100	WC	[40]
Med CS	2	760-1120	67-150	WC	[45]
Low/Med/High CS	1.6	400	100-400	WC	[21]
Low/Med/High CS	1.6	400	25-400	WC	[23]
Low/Med/High CS	1.3	400	100-400	WC	[36]
Low/High CS	4	800	200	PCBN	[61]
Medium CS	2	300	150	WC	[62]
Medium CS	2	650	250	Si3N4	[62]
Low/High CS	4	400-800	200	PCBN	[64]

Cheng et al. examined the parameters of welding ferrite-ductile iron and low-carbon steel under different situations. Joining dissimilar materials with FSW at 982 revolutions per minute and 72 millimeters per minute has resulted in faultless welds. [42]

Thin sheets of SK4 (a high-carbon steel alloy, 2 mm thick, 0.95 percent carbon) were welded using FSW by Khodir et al. The welding instrument has a 12 mm-wide shoulder and a 4 mm-wide probe. The WC component of the alloy ensured its durability. The normal axis of the tool was angled outward by 31 degrees. When the rotation speed went from 100 to 400 revolutions per minute, the welding speed remained constant at 100 mm per minute. SZ made at 100 rpm had a slightly higher consistent hardness than BM made at the same speed. When the stir zone rotation speed was increased to over 100 rpm, a large disparity appeared between the top and bottom surfaces, indicating an increase in hardness. At 400 rpm, the maximum hardness value of approximately 820 HV was achieved towards the top surface of the SZ that was formed. [43]

In this study, the microstructure and strength characteristics of aluminum alloy 6061-T6 friction stir-welded to ultra-low carbon steel were examined utilizing a range of advance rates at a constant rotation rate of 1200 rpm. The corresponding advance rates were 100, 200, and 400 mm/min. X40CrMoV51 steel was used for the FSW tool's fabrication. (After being quenched, the temperature was reduced to 50 HRC) The friction stir welding method may be used to join a variety of 6061-T6 aluminum alloys to ultra-low carbon steel, according to the study's findings. Moreover, it has been proven that raising the IMC layer thickness causes a decrease in welding speed, which has been proved to have a significant effect on joint strength. [44]

On a plate made of carbon steel, friction stir welding was performed using a tool made of tungsten carbide at tool rotation and traversal rates ranging from 760 to 1120 revolutions per minute and 67 to 150 millimeters per minute, respectively. The experiment showed that ferrite grains were more likely to be made when the tool rotated quickly and moved slowly. Even so, grain growth in the HAZ made it so that the strength of standard specimens was less than that of the parent alloy. [45]

When investigating AISI 1018 with FSW, Bhatia et al. used tungsten carbide that had 7% cobalt in their research. Both the joint's microstructure and its mechanical properties were looked into to learn more about how well it works. A friction stir welded connection was created with the tool rotating at 450 revolutions per minute, the travel speed being 60 millimeters per minute, and the shoulder diameter being 20 millimeters. Since there were no obvious cracks in the area, the new joint gave the impression that it was perfect. When they were present, dendrites prevented extension from occurring. [46]

A hybrid FSW technique was made to cut down on tool load and, in turn, weld faults. In this approach, the FSW was performed after the local heating with the laser heat source illustrated in Figure 4. This was done in order to improve the quality of the weld. A carbon steel was welded with the use of this approach, and the results were subjected to rigorous quality control testing. The microstructure of the joint bears a striking resemblance to that of a conventional friction stir welded connection. The fact that hybrid FSW joints can be welded more quickly than normal FSW joints permits them to have a strength that can be greater than that of standard FSW joints. [47]

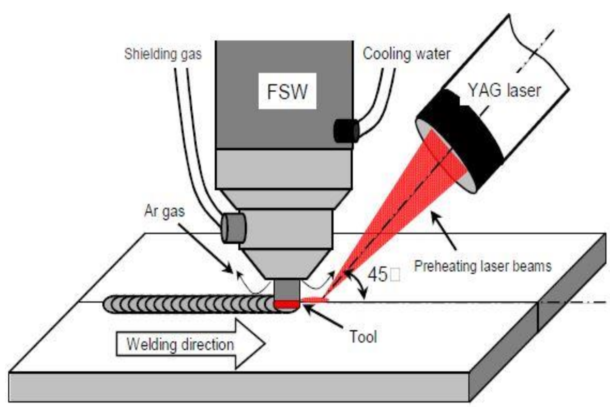

Fig.4 Schematic sketch of Hybrid FSW. [47]

Yufeng Sun et al. have successfully performed double-sided FSW welding on 40-mm-thick low-carbon steel plates. Using a PCBN rotating device, following optimization, the travel speed of the rotating tool was fixed at 25 mm/min and the rotation speed was set to 150 rpm. The first-pass FSW had no significant effect on the second-pass FSW since the welding conditions were identical for both passes. Figure 5 depicts that the mechanical properties of the SZ were superior to those of the BM, with hardness and tensile strength increasing progressively from the BM to the SZ. [48]

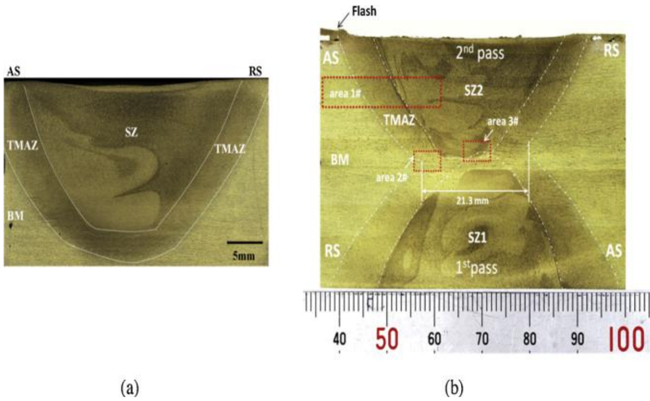

Fig. 5. Optical Microscope of the joint's cross-sectional macrograph after (a) the first FSW pass and (b) the second FSW pass. [48]

In this study, 4 mm thick medium carbon steel (JIS-S45C) plates were fused using linear friction welding (LFW). To study the impacts of the material parameters on the welding temperature at a low frequency, low amplitude, and strong applied pressure, LFW processing was carried out at different applied pressures with a constant applied pressure and at varied applied pressures with a constant frequency. To accomplish combining by recrystallization on medium-carbon steel, LFW was employed to inject severe plastic deformation into the joint contact at a low temperature, as seen in Figure 6. [49]

TABLE III
HIGH/ULTRAHIGH CARBON STEEL PARAMETERS

Work piece	Thk (mm)	Rotation Speed (RPM)	Welding speed (mm/ min)	Tool	Ref
S70c High CS	1.6	100-800	25-400	WC	[22]
High CS	1.6	100-900	25-425	WC	[25]
Ultra high-CS	2.3	400-800	76	PCBN	[27]
High CS	1.6	100-400	100-200	WC	[28]
SK 5 High CS	4	700	80	WC-Co	[29]
SK 4 High CS	2	100-400	100	WC	[43]
SUJ2Ultra high CS	2.3	400-800	76.2	PCBN	[56]
SK85M High CS	3	100-500	50-150	WC-Ni	[57]
SK 4 High CS	2	120	100	WC	[68]

Using a W-Re PCBN (polycrystalline cubic born nitride PCBN) tool, plates of 6mm thick mild steel (A 516 Gr.60 N) and Ni-based alloy 625 (A 625) were subjected to friction stir welding. Using a tool with a rotational speed of 300 rpm and a travel speed of 100 mm/min, the FSW of mild steel and the Ni-based alloy 625 produce sound welds devoid of volumetric flaws. While friction stir welding aluminum alloy to carbon steel, Karimi et al. employed two distinct tool materials (HSS and WC) and offset while keeping a consistent tool speed and feed rate of 710 rpm and 28 mm/min, respectively. The outcome of the experiment is that tungsten carbide (WC) tool material with a 1 mm offset on the aluminum alloy area performed superiorly. [51]

Kaushik et al. performed friction stir welding using three distinct tools to connect 3 mm of mild steel and aluminum alloy. This study studied the influence of shoulder diameter and pin shape on the establishment of stir zones and joint tensile strength. [52]

Avinish et al. examined a tungsten carbide tool for performing dissimilar friction stir welding between 4 mm-thick plates of stainless steel (UNS S30400) and mild steel (UNS G10080). Regarding the mechanical properties of welded joints, such as hardness, tensile strength, and impact toughness, the impacts of tool rotating speeds (600, 875 rpm) and tool offsets (0.6, 1.2 mm) were studied. When tool rotational speed and tool offset distance increased, it was discovered that the YS and UTS of the joints increased. [53]

TABLE IV
DISSIMILAR CARBON STEEL PARAMETERS

Workpiece	Thk (mm)	Rotation Speed (RPM)	welding speed (mm/min)	Tool	Ref
ST 37 Low CS /SS 304	3	600	50	WC-Co	[33]
SMA490 – AW/SPA-H Low CS	3	150	80	WC	[39]
Q 235 Low CS/SS 304 304	3	475	47.5	WC-Co	[41]
Ductile Iron /Low CS	3	982	72	WC-Mo	[42]
AISI 1045/Al 1100	3	710	28	HSS/ WC	[51]
AI 5052/MS	3	386	40	WC	[52]
SS/MS	2	600 & 875	90	WC	[55]
ST 37/ ST 52	4	630	65	WC	[59]
AZ31B/SS 400	3	400	72-96	WC	[60]
ST 37 Low CS /SS 304	3	400&800	50	WC-Co	[65]
Low CS / SS 304	10	500& 1000	100	W-Re-HfC	[70]

Venkatesh et al. say that the development of polycrystalline cubic boron nitride (PCBN) and tungsten alloy tool materials made it possible for FSW to be used on stainless steel, hardened steel, and super alloys with better weld strength, mechanical properties, and microstructural features. [54]

Husain et al. welded carbon steel using carbide tools at varied tool rotational rates (800–1000–1200–1400 rpm) while maintaining other factors, such as the welding speed of 50 mm/min, constant. It was investigated how the grain structure and texture of weld nuggets evolved. [55]

To incorporate ultrahigh carbon steels into commercial bearing steel (SUJ2: Fe-1.02wt%C-0.24wt%Si-0.37wt%-Mn-1.42wt%Cr), Yukata et al. developed a PCBN tool. In this experiment, welds were made from ultrahigh-carbon steel at 400, 600, and 800 revolutions per minute. The steady rate of the tool's motion was 1.27 millimeters per second. At any rpm, FSW performed flawless welds in ultrahigh-carbon steels. The martensitic nature of all the welds contributed to their exceptional hardness. [56]

They used a displacement-controlled FSW machine and WC-Ni alloy tools to weld high-carbon steel (JIS SK85M) by Buchibabu et al. For each welding combination, we welded at 100/50, 300/50, 300/150, and 500/50 RPM with the given tool rotational speed and welding speed. The effects of chromium and titanium additions on the microstructure and mechanical characteristics of steels with a carbon content of 0.4% were studied after FSW. Microstructures in the stir zones of chromium-free, chromium-1%, and chromium-4% FSWE medium-carbon steels are ferrite and pearlite, bainite, and completely lathed martensite, respectively. [57-58]

Butt welding of low-carbon steels with variable carbon content, including 4 mm-thick plates of St37 and St52 steel, was accomplished with a tungsten carbide torch and FSW. Both the tool's rotating speed and its traverse speed remained at a constant 630 rpm and 65 mm/min during the whole FSW process. There were no weld defects in the factory-made connection. For this reason, the weld region of the joint is harder than the surrounding material since this is where phase changes and grain refinement occurred. [59]

Fig.6 Linear FSW and specimen location. [49]

Joo employed a hybrid gas tungsten arc-friction stir welding (HGTAFSW) technique to combine 4 mm of dissimilar magnesium alloy (AZ31B) and mild steel (SS400). This technique used prior gas tungsten arc welding (GTAW) to warm a mild steel plate surface during friction stir welding (FSW). HGTAFSW, which entailed heating a mild steel plate with a GTAW preheating source, generated welds that were more mechanically sound and devoid of metallurgical flaws when compared to FSW. [60].

Choi et al. did the different FSW of two carbon steels, SPHC (0.04% C) and SK5 (0.841% C), in two different situations with different fixed locations of the welded parts. Both scenarios were successfully completed using the PCBN tool with no welding errors. On the microstructural evolution of grain size and phase shift during FSW, research and analysis were conducted. [61]

To find out how laser preheating affects flaw formation and tool torque during friction stir welding (FSW) of carbon steel using x-ray radiography shown in figure 7 , a cross-sectional inspection of the stir zone, a measurement of the tool's rotating torque, and a three-dimensional visualization of the material flow were done. For both the silicon nitride and cemented carbide tools, the welding speed, tool rotation speed, and tool load were kept at 300 mm/min, 150 rpm, and 29 kN. [62]

The current study demonstrated that FSW can weld low-carbon steel without flaws when using a tungsten carbide WC-10 wt.% Co-based tool. Successful joints have been created with enhanced mechanical characteristics. The yield strength and ultimate tensile strength of the welded samples were both greater than the hardness of the base material. In contrast to the basic material, there was a decrease in the percentage of elongation up to fracture. [63]

Friction stir welding was used by Choi et al. to assess the microstructure and mechanical characteristics of various low-carbon (SPHC) and high-carbon (SK85) steel alloys. FSW was carried out using a movement speed of 200 mm/min and two tool rotation rates of 400 and 800 rpm. The hardness dispersion further demonstrated that hardness was lower at higher tool rotation rates than at slower tool rotation speeds due to varying volume percentages of the martensitic phase. The test specimen cracked in the SPHC BM region following the tensile test and displayed the same yield strength (YS) and ultimate tensile strength (UTS) as SPHC BM. [64]

To join plates of 304 stainless steel and St37 steel that were both 3 mm thick, Jafarzadegan et al. employed friction stir welding at 50 mm/min with tool rotational rates of 400 and 800 rpm. As a result of recrystallization in 304 steel and modifications in st37 steel, the weld area hardened, enhancing the joint's capacity to endure tensile stresses. [65]

Hot-rolled Q235 mild steel plates for FSW butt welding with diameters of 100 mm, 60 mm, and 3 mm were the subject of research by Wang et al. The FSW method was performed on a modified vertical milling machine with uniaxial compression at 47.5 mm/min for welding and 475 rpm for rotating. The direction of the plate rolling and the orientation of the welding were parallel. 0.2 mm shoulder plunge depth, 2° tilt, and 20 kN welding pressure The results showed that following the FSW, the heat-affected zone (HAZ) of the retreating side and the HAZ of the advancing side were able to recover due to the impact of the heating cycle. The FSW joints had outstanding bending capabilities as well. [66]

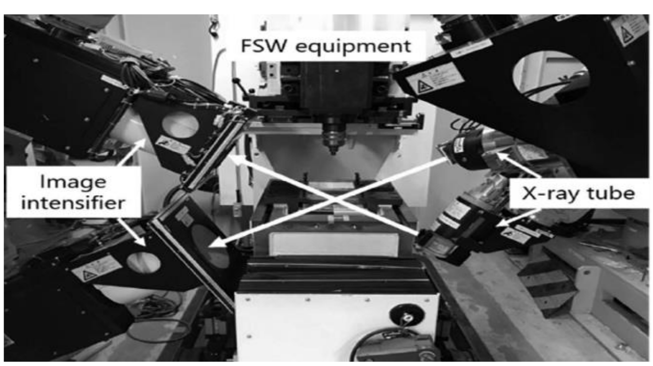

Fig.7 X-ray radiography with FSW [62]

Husain and his colleagues used FSW to join plates of carbon steel by changing the speed at which the tools turned. The things that caused different phases to happen in different places were looked at. Using thermal and mechanical data, a number of welding situations were analyzed. The weld nugget reached temperatures of 1300–1360 K at its hottest throughout the welding process. The weld generated at a tool rotational velocity of 1000 rpm with the required elasticity had the maximum tensile strength of the joints. The effectiveness of the joint was affected by varying the tool speed after 1000 rpm. [67]

Joints made of high carbon steel (SK 4) using the friction stir welding technique were examined for their microstructure and mechanical properties. The welds were protected from oxidation by using a shielding gas of argon while they were being made. Figure 8 shows the results of our analysis and comparison of the welds' sensitivity to HE in terms of hydrogen blistering and hydrogen-induced cracking, both of which were accomplished by the use of the hydrogen cathodic charging method and subsequent tensile testing. [68]

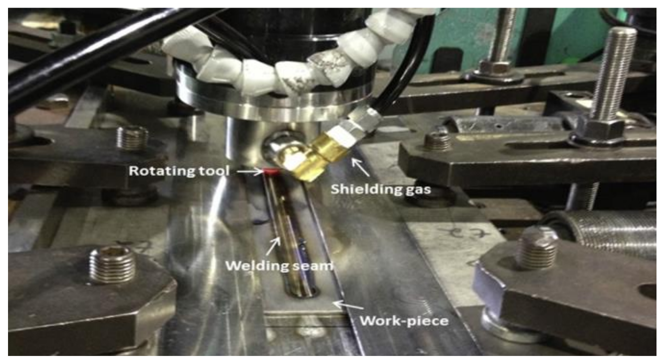

Fig. 8. FSW process with Shielding gas. [68]

In this study, the mechanical properties of the butt joints made from hot-rolled structural steel grade St52 (EN S355JR grade) plates with thicknesses of 200 mm, 45 mm, and 4 mm were carefully looked into.FSW was utilized to successfully and flawlessly assemble connections between plates of St52 steel. [69]

In combining specimens made of carbon steel (CS) and stainless steel (SS) 316), Bin Matlin et al. employed friction stir welding and double-sided butt joints. Studies were conducted to determine how the tool rotational speed and specimen preheating temperature influenced the final microstructure and mechanical behavior. The experiment employed a constant moving speed of 100 mm/min, tool rotational speeds of 500 and 1000 rpm, and preheating temperatures of 50 and 100 C. [70]

Syed et al. welded thermoplastic shell and tube heat exchangers tube to tubesheet. The effectiveness of FSW joints was assessed using tube pullout tests and fractographic analyses. [71]

III. Conclusion

In this study, we looked at the work of a number of authors, each of whom focused on a different part of the FSW approach as a process variable. The results and suggestions are included in this review of research, which also favors them.

1. Controlling the welding process parameters is important if you want to successfully join two different types of metal. If you want a high-quality weld, you need to give some thought to the process parameter to use. Heat input and cooling rate, both of which are controlled by process parameters, determine the microstructure and mechanical qualities. As rotation speed and welding speed influence the mechanical and metallurgical properties of joints, they are both important for achieving a flawless weld, as shown by the research results.

2.The tools used for welding steel must be extremely durable, robust, strong, and resistant to fracture. The practicality of FSW for a broad variety of alloys has been demonstrated, and tungsten-based materials and PCBN are routinely used tool materials for FSW of similar or dissimilar joints between any grades of carbon steel.

3. Most studies seem to have focused on different friction stir welding processes for carbon steel, but both basic and advanced nondestructive tests have been ignored. There isn't a lot of research literature about non-destructive testing on carbon steel friction stir welds. So, looking into non-destructive techniques for similar or different joints in all grades of carbon steel could lead to better weld quality in oil and gas fields and better material joint performance.

4. A thorough examination is required for the purpose of determining how preheating and post-weld heat treatment affects the mechanical and metallurgical behavior of FSW joints manufactured from any grade of carbon steel.

5. In terms of process performance parameter selection for FSW for carbon steel, there are no adequate recommendations or references for choosing input parameters to create the desired output.

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