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DOUBLE FILLET WELDING OF CARBON STEEL T-JOINT BY DOUBLE CHANNEL SHIELDING GAS METAL ARC WELDING METHOD USING METAL CORED WIRE

Low carbon steel material and T-joints are frequently used in ship building and steel constructions. Advantages such as high deposition rates, high quality and smooth weld metals and easy automation make cored wires preferable in these industries. In this study, low carbon steel materials with web and flange thicknesses of 6 mm, 8 mm and 10 mm were welded with conventional GMAW and double channel shielding gas metal arc welding (DMAG) method to form double fillet T-joints using metal cored wire. The difference between these two methods were characterized by measurements of mean welding parameters, Vickers hardness profiles, weld bead and HAZ geometry of the joints and thermal camera temperature measurements. When weld bead and HAZ geometries are focused, it was seen filler metal molten area increased and base metal molten area decreased in DMAG of low carbon steel. When compared with traditional GMAW, finer and acicular structures in weld metal and more homogenous and smaller grains in HAZ are obtained with double channel shielding gas metal arc welding.

Keywords: Double channel torch; low carbon steel; metal cored wire; T-joint; microstructure

1. Introduction

T-joints are used in manufacturing and heavy industries widely and they are generally formed with gas metal arc welding (GMAW) using either solid or cored wires. Due to their high deposition rates, cored wires shorten manufacturing cycles and are extensively utilized in these industries. GMAW has been researched extensively by a number of researchers unlike double channel shielding gas metal arc welding (DMAG) method. Principle of DMAG has been explained by Mert et al. [1]. Schematic representation of DMAG is shown in Fig. 1.

Literature research shows limited number of studies on independent flow of dual shielding gas supply in gas metal arc and gas tungsten arc welding methods. Some researchers have investigated supply of double shielding gas in gas tungsten arc (GTA) welding and they have studied double shielded GTA

method to improve weld penetration as well as the effect of flow ratio between inner and outer layers of the shielding gas on the fusion zone profile. They have also researched critical oxygen content in the weld pool in double shielded GTA welding to increase weld depth and also weld pool shape variations and electrode oxidation and protection [3-7].

In contrast, some other researchers have investigated DMAG method. They have focused on seam geometry, metal transfer, spatter loss and porosity in DMAG welding using solid and cored wires [8-9]. Other researchers have also studied spatter amounts in nozzles of DMAG welding torches [10-11]. DMAG welding of aluminum has also been investigated [12]. Shielding gas flow in inner and outer channels of DMAG torch has been researched and reported flow to be less turbulent compared with single channel flow [13]. DMAG welding of austenitic stainless steel with 10 mm thickness using cored wire to form double fillet

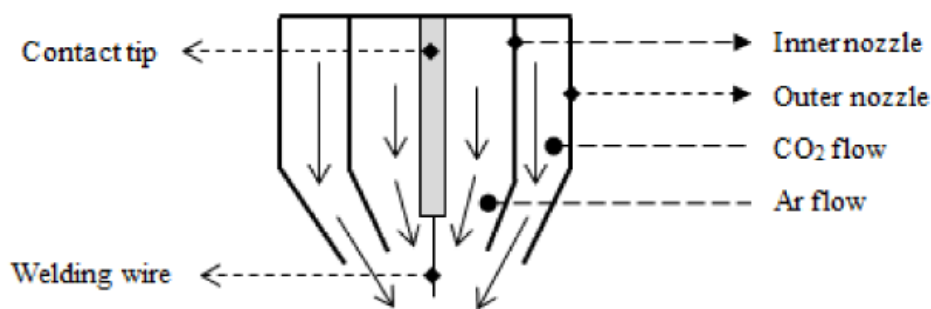


Fig. 1. Schematic representation of DMAG method [2]

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T-joint has been investigated by Mert et al. [1].

In this paper, in order to form double fillet welded T-joints of low carbon steel with different thicknesses, i.e. 6 mm, 8 mm and 10 mm, DMAG and conventional GMAW were utilized using metal cored wire. Mean welding parameters and heat input, thermal camera temperature measurements and Vickers hardness profiles, weld metal, HAZ, base metal molten and filler metal molten area measurements as well as microstructures were compared between these two methods.

2. Experimental

Low carbon steel material with 6 mm, 8 mm and 10 mm thicknesses was used along with metal cored wire (EN ISO 17632: T 42 3 M M H8) with 1.2 mm diameter and double channel shielding gas metal arc welding torch in order to form unrestricted T joints with 100 mm × 200 mm web and 200 mm × 200 mm flange. Chemical composition of base metal and filler metal are given in Table 1. Power source, wire feed unit, torch manipulator, DMAG torch, gas mixers were same as the ones used in previous studies [1, 2, 11]. Experimental setup is shown in Fig. 2.

TABLE 1

Chemical compositions of low carbon steel S235JR (EN 10025) with 6 mm, 8 mm and 10 mm thicknesses and metal cored filler metal (% wt.)

| Material | %C | %Mn | %Si | %P | %S | %Cu | %Al |
|--------------------------|-------|-------|-------|-------|-------|-------|-------|
| S235JR [6 mm] | 0.060 | 0.550 | 0.140 | 0.013 | 0.022 | 0.050 | 0.034 |
| S235JR [8 mm] | 0.077 | 0.689 | 0.137 | 0.011 | 0.006 | 0.007 | 0.040 |
| S235JR [10 mm] | 0.094 | 0.729 | 0.191 | 0.016 | 0.004 | 0.017 | 0.048 |
| Metal cored filler metal | 0.05 | 1.50 | 0.65 | <0.01 | <0.02 | — | — |

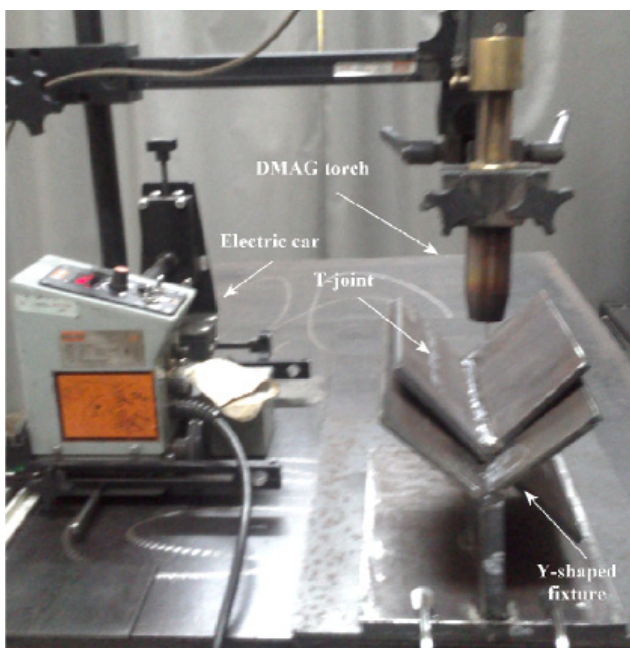


Fig. 2. Experimental setup [1]

Total shielding gas flow rate was 15 L min⁻¹. Shielding gases used were 40%Ar-60%CO₂ mix for 6 mm thickness, 50%Ar-50%CO₂ mix for 8 mm thickness and 60%Ar-40%CO₂ mix for 10 mm thickness in conventional GMAW, whereas in DMAG method, corresponding to the same flow rate as in GMAW, shielding gas flow in inner channel of the double shielding gas torch was 6 L min⁻¹ Ar and 9 L min⁻¹ CO₂ in outer channel, 7.5 L min⁻¹ Ar in inner channel and 7.5 L min⁻¹ CO₂ in outer channel, 9 L min⁻¹ Ar in inner channel and 6 L min⁻¹ CO₂ in outer channel, respectively.

Preliminary tests were realized in order to obtain calculated design leg lengths of 4.5 mm, 6 mm and 7.5 mm for 6 mm, 8 mm and 10 mm thicknesses, respectively. When desired weld sizes were achieved, parameter settings were recorded (i.e., wire feed rates of 9.55 m min⁻¹, 10.51 m min⁻¹, 12.01 m min⁻¹; welding speeds of 47 cm min⁻¹, 43 cm min⁻¹, 34 cm min⁻¹, respectively). Electrode extension of 19 mm was fixed during the tests.

During welding, temperatures were recorded with FLIR A320 thermal camera (Fig. 3). Temperature recording via thermal camera lasted around two minutes. Thermal camera temperature measurement points are shown in Figure 3 and these points (i.e. points 6, 7, and 8) are in the middle of the joint and in HAZ and its vicinity. Closest point to weld seam is point 6. There is 3 mm distance between each apparent temperature measurement points.

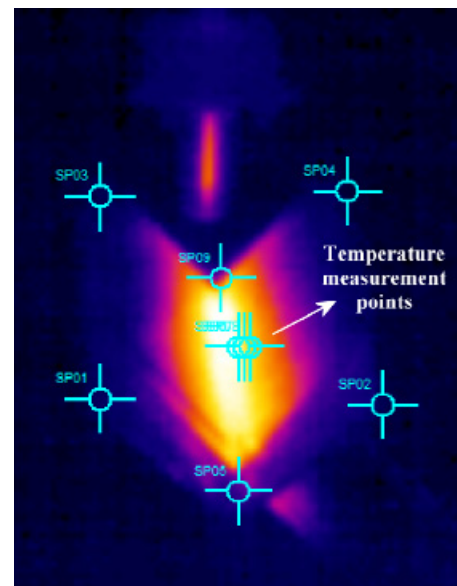


Fig. 3. Apparent temperature measurement points for T-fillet joints

Small T-fillet macro and hardness samples involving base metal, weld metal and HAZ were extracted from T-fillet welded joints after welding was finished. Samples ground with SiC sand papers in several steps and then polished with diamond paste. Before Vickers hardness measurements, samples were micro etched. 5 hardness measurements from each zone (i.e. base metal, HAZ, weld metal, HAZ and base metal) with a total of 25 measurements for each welded sample were realized. There was 0.5 mm distance between measurement points for base metal and weld metal hardness measurements; whereas the distance

between two measurement points was 0.25 mm for HAZ because it was narrower compared with base metal and weld metal. Fig. 4 presents hardness measurement locations in the joint. Completing these measurements, samples were macro etched and then, weld metal, HAZ, base metal molten and filler metal molten area measurements were realized via computer software.

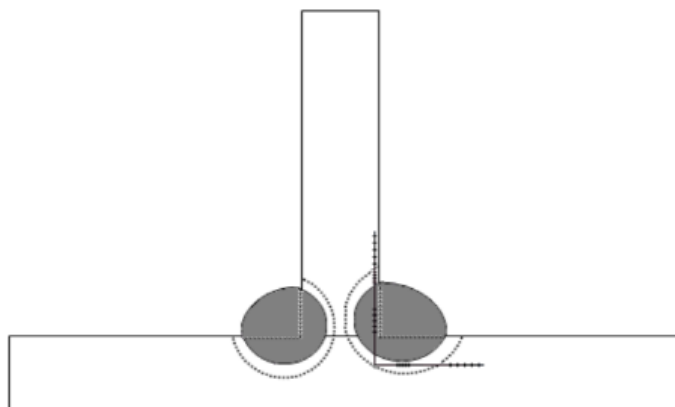


Fig. 4. Hardness measurement locations in the joint

3. Results and discussion

It was observed that generally mean currents were higher and mean voltages were lower in DMAG compared with conventional GMAW but differences were more significant in current values (Table 2). Total heat inputs in two passes were generally 3% to 6% higher in DMAG compared with traditional GMAW, mainly because of higher current values recorded.

Fig. 5 introduces apparent temperatures measured in T-fillet joint with 6 mm thickness, for points 6, 7 and 8 were 1216°C, 735°C and 480°C with the use of traditional GMAW (40% Ar-60% CO₂) and 823°C, 528°C and 448°C with the use of DMAG (6 L min⁻¹ Ar – 9 L min⁻¹ CO₂), respectively. Cooling of points 6, 7, and 8 down to 400°C from maximum temperatures reached

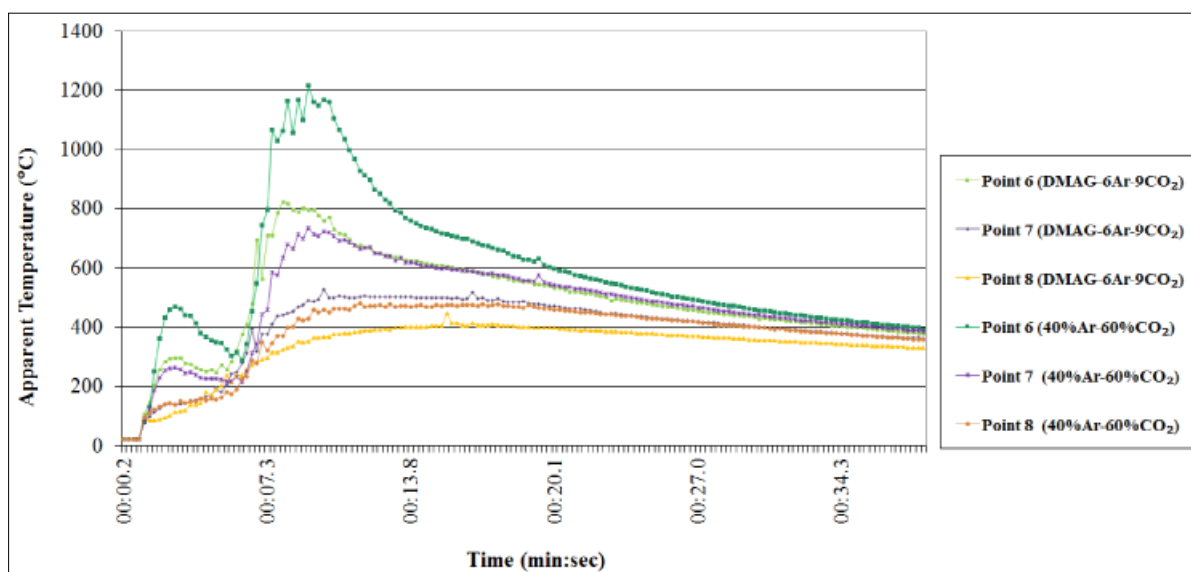


Fig. 5. Apparent temperature – time graph of T-fillet joint with 6 mm thickness welded with DMAG-6Ar-9CO₂ and 40% Ar-60%CO₂,

TABLE 2

Mean welding parameters, heat input energies and total heat inputs for double fillet welded T-joints using metal cored wire

| Thickness [mm] | Shielding Gas Supply | Current [A] | Voltage [V] | Welding speed [mm.min ⁻¹] | Heat input for 1 pass [kJ.mm ⁻¹] | Total heat input [kJ] |
|----------------|---|-------------|-------------|---------------------------------------|--|-----------------------|
| 6 | 40% Ar – 60% CO ₂ | 225 | 30.9 | 470 | 0.797 | 318.9 |
| | DMAG – 6 L min ⁻¹ Ar – 9 L min ⁻¹ CO ₂ | 224 | 30.5 | 470 | 0.785 | 314 |
| 8 | 50% Ar – 50% CO ₂ | 235 | 29.6 | 430 | 0.872 | 348.8 |
| | DMAG – 7.5 L min ⁻¹ Ar – 7.5 L min ⁻¹ CO ₂ | 252 | 29.2 | 430 | 0.924 | 369.5 |
| 10 | 60% Ar – 40% CO ₂ | 267 | 31.2 | 340 | 1.321 | 528.4 |
| | DMAG – 9 L min ⁻¹ Ar – 6 L min ⁻¹ CO ₂ | 278 | 31 | 340 | 1.364 | 545.6 |

took 28.7 s, 27.1 s and 18.8 s with the use of traditional GMAW and 27 s, 21 s and 3.9 s with the use of DMAG, respectively. As a consequence, calculated cooling rates of these apparent temperature measurement points were 28.4°C s⁻¹, 12.4°C s⁻¹ and 4.3°C s⁻¹ with the use of conventional GMAW and 15.7°C s⁻¹, 6.1°C s⁻¹ and 12.3°C s⁻¹ with the use of DMAG, respectively.

Fig. 6 presents Vickers hardness graph for T-fillet joints with 6 mm thickness welded with DMAG – 6 L min⁻¹ Ar – 9 L min⁻¹ CO₂ and 40% Ar-60% CO₂. It can be seen weld metal and HAZ hardness values were slightly higher with DMAG.

Fig. 7 shows apparent temperatures measured in T-fillet joint with 8 mm thickness, for points 6, 7 and 8 were 951°C, 555°C and 412°C with the use of traditional GMAW (50% Ar-50% CO₂) and 1125°C, 609°C and 425°C with the use of DMAG (7.5 L min⁻¹ Ar – 7.5 L min⁻¹ CO₂), respectively. Cooling of points 6, 7, and 8 down to 400°C from maximum temperatures

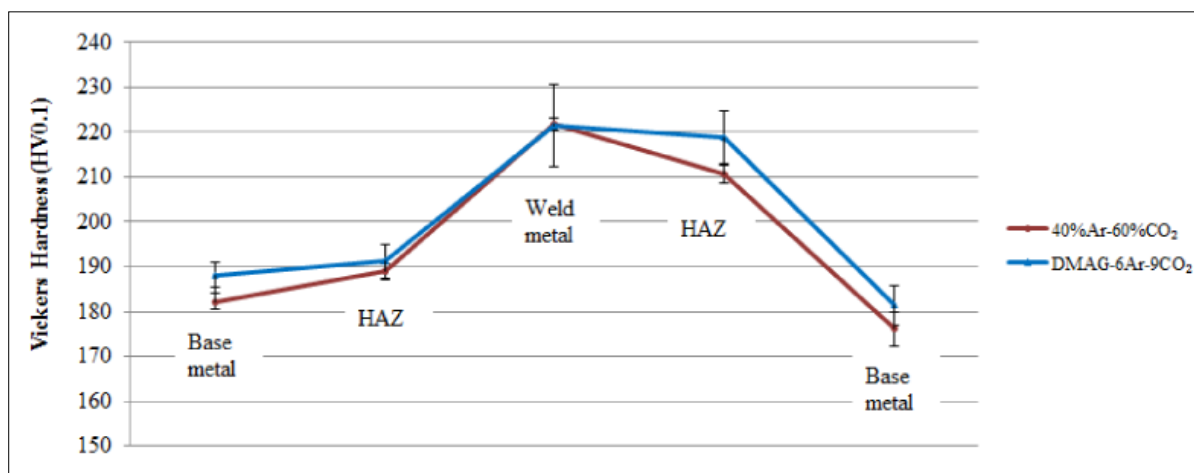


Fig. 6. Vickers hardness graph of T-fillet joint with 6 mm thickness welded with DMAG-6Ar-9CO₂ and 40%Ar-60%CO₂

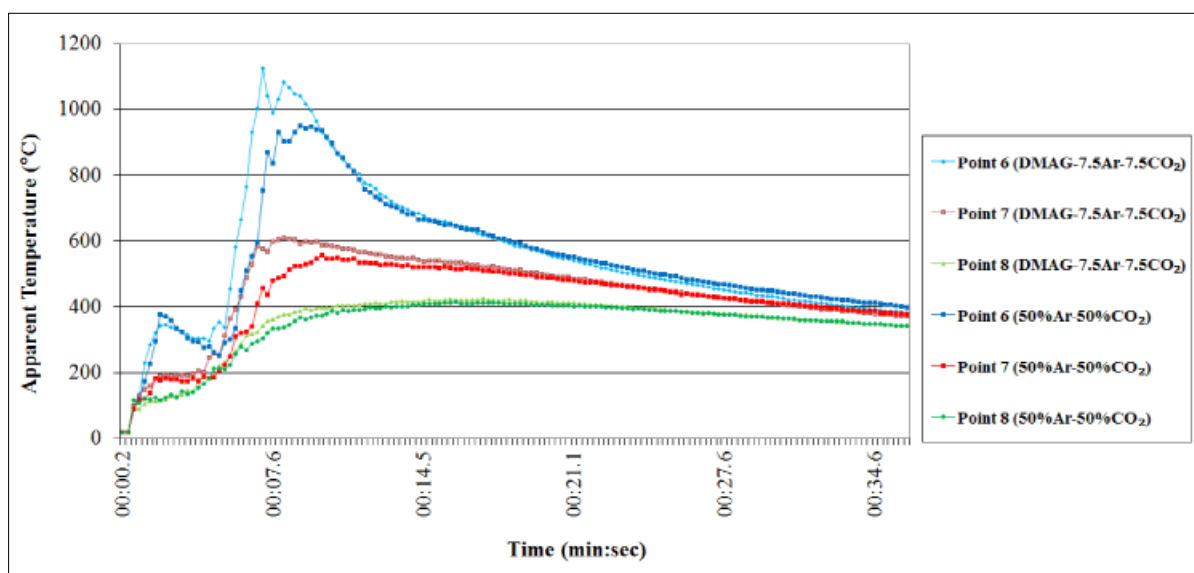


Fig. 7. Apparent temperature – time graph of T-fillet joint with 8 mm thickness welded with DMAG-7.5Ar-7.5CO₂ and 50%Ar-50%CO₂

reached took 27.5 s, 22.2 s and 6.6 s with the use of traditional GMAW and 26.7 s, 23.3 s and 6.4 s with the use of DMAG, respectively. As a consequence, calculated cooling rates of these apparent temperature measurement points were 20.0°C s⁻¹, 7.0°C s⁻¹ and 1.8°C s⁻¹ with the use of conventional GMAW and 27.1°C s⁻¹, 9.0°C s⁻¹ and 3.9°C s⁻¹ with the use of DMAG, respectively.

Fig. 8 depicts Vickers hardness graph for T-fillet joints with 8 mm thickness welded with DMAG – 7.5 L min⁻¹ Ar – 7.5 L min⁻¹ CO₂ and 50%Ar-50%CO₂. Measured weld metal and HAZ hardness values were higher with DMAG process. Since temperature measurement points reached higher temperatures with DMAG, austenite structure dissolved more elemental carbon. In addition to this, cooling rates were higher with DMAG. As a consequence, hardness values were considerably higher compared with conventional GMAW.

Fig. 9 presents apparent temperatures measured in T-fillet joint with 10 mm thickness, for points 6, 7 and 8 were 1300°C, 1133°C and 658°C with the use of traditional GMAW (60%Ar-40%CO₂) and 888°C, 510°C and 394°C with the use of DMAG

(9 L min⁻¹ Ar – 6 L min⁻¹ CO₂), respectively. Cooling of points 6, 7, and 8 down to 400°C from maximum temperatures reached took 32.5 s, 35.7 s and 32 s with the use of traditional GMAW, respectively. Since apparent temperature for point 8 did not reach over 400°C, cooling times only for points 6 and 7 were 29.6 s, 23.8 s with the use of DMAG. As a consequence, cooling rates of these apparent temperature measurement points were 27.7°C s⁻¹, 20.5°C s⁻¹ and 8.1°C s⁻¹ with the use of conventional GMAW, respectively. Again cooling rates were 16.5°C s⁻¹, 4.6°C s⁻¹ only for points 6 and 7 with the use of DMAG.

Fig. 10 shows Vickers hardness graph for T-fillet joints with 10 mm thickness welded with DMAG – 9 L min⁻¹ Ar – 6 L min⁻¹ CO₂ and 60%Ar-40%CO₂. It can be seen weld metal and HAZ hardness values were slightly higher with DMAG.

Table 3 presents weld metal, HAZ, base metal molten and filler metal molten area measurements for T-fillet joints with 6 mm, 8 mm and 10 mm thicknesses. HAZ and filler metal molten areas were bigger and base metal molten areas were smaller with the use of DMAG – 6 L min⁻¹ Ar – 9 L min⁻¹ CO₂ and

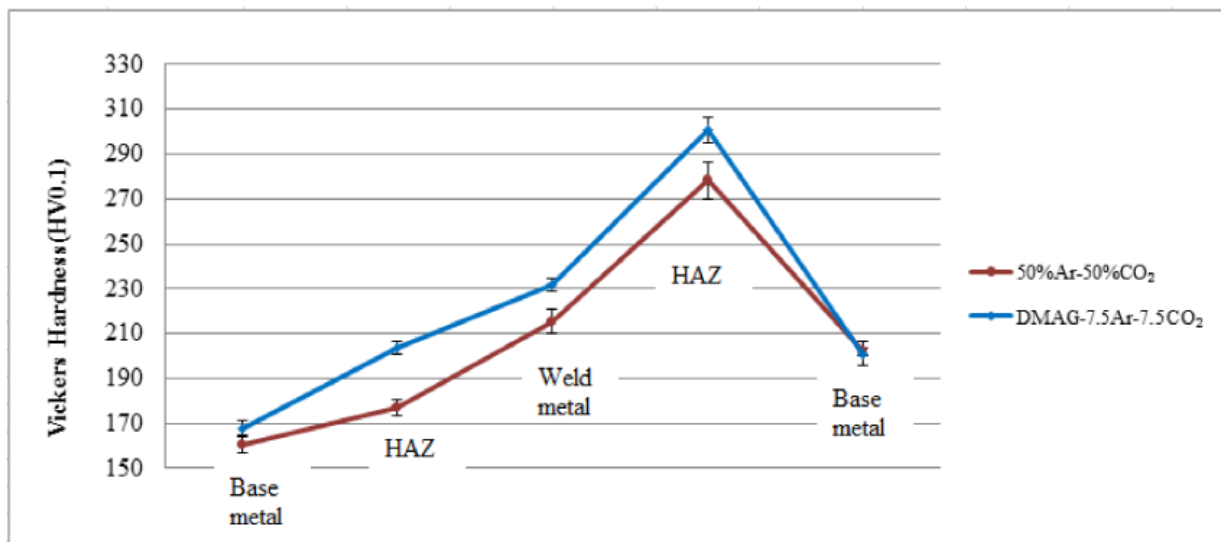


Fig. 8. Vickers hardness graph of T-fillet joint with 8 mm thickness welded with DMAG-7.5Ar-7.5CO₂ and 50%Ar-50%CO₂

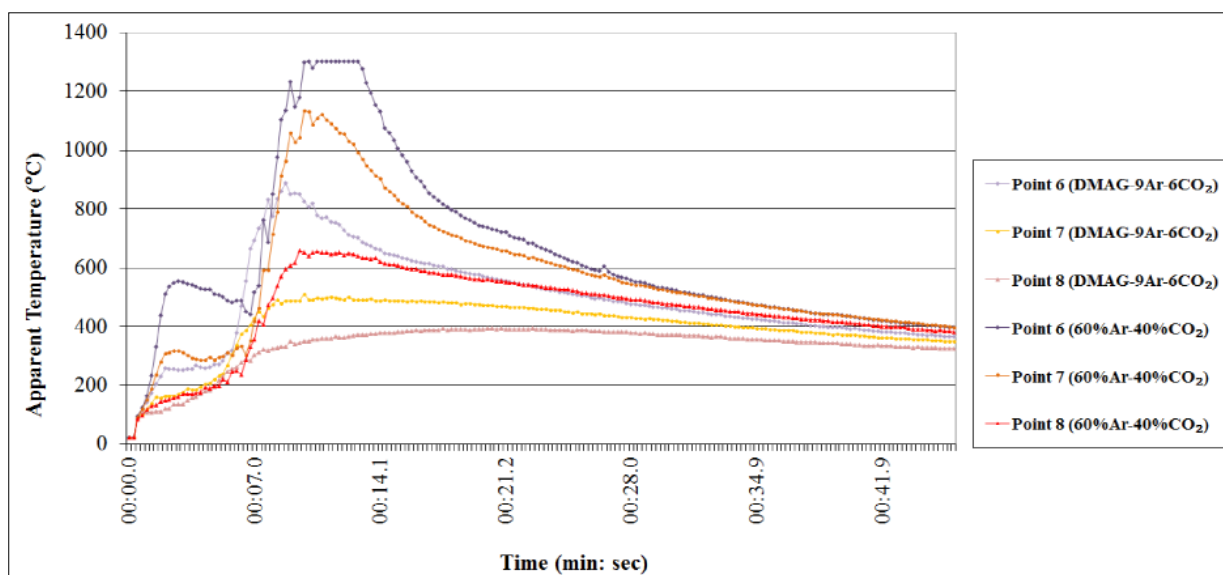


Fig. 9. Apparent temperature – time graph of T-fillet joint with 10 mm thickness welded with DMAG-9Ar-6CO₂ and 60%Ar-40%CO₂

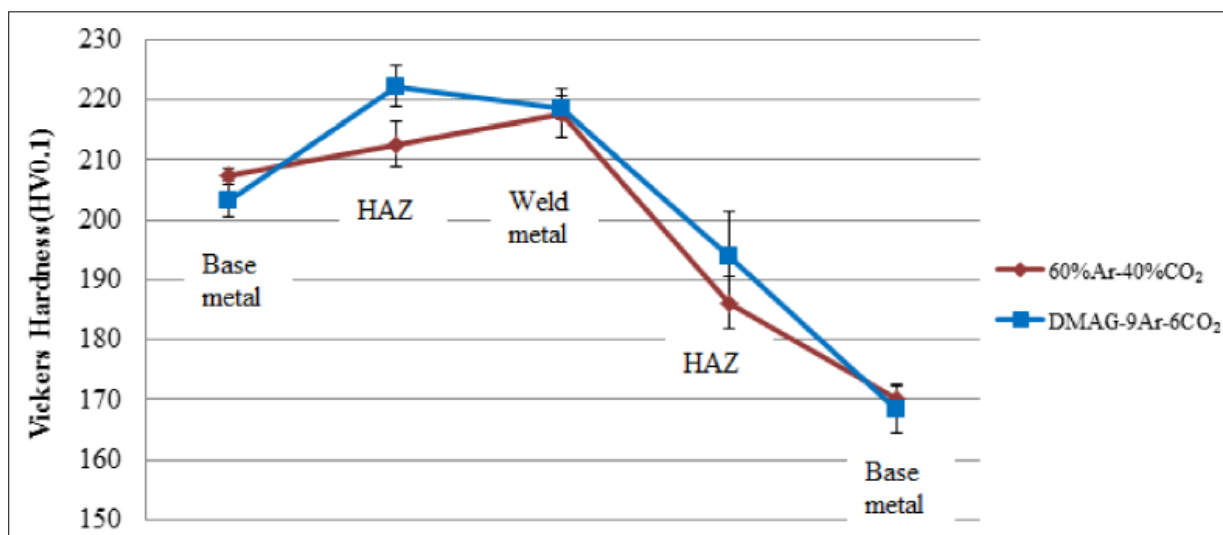


Fig. 10. Vickers hardness graph of T-fillet joint with 10 mm thickness welded with DMAG-9Ar-6CO₂ and 60%Ar-40%CO₂

DMAG – 7.5 L min⁻¹ Ar – 7.5 L min⁻¹ CO₂ compared with corresponding conventional mix gas ratios. Filler metal molten area increased 14% with the use of DMAG with equal argon and CO₂ ratios compared with traditional mix gas method. When argon was increased, it was observed HAZ area was smaller with the use of DMAG – 9 L min⁻¹ Ar – 6 L min⁻¹ CO₂ compared with traditional mix gas, 60%Ar-40%CO₂. As observed in previous DMAG gas ratios, base metal molten area was smaller and filler metal molten area was bigger with the use of DMAG – 9 L min⁻¹ Ar – 6 L min⁻¹ CO₂.

When weld metal microstructures of low carbon steel welded with different parameters using traditional GMAW and DMAG are compared, generally, finer and acicular structures are observed with DMAG. Whereas, microstructures obtained with conventional GMAW are generally coarser (Fig. 12, 14, 16).

When HAZs obtained with the use of both methods are compared, it is seen that microstructure is more homogenous and grains are smaller in size with the use of DMAG (Fig. 11, 13, 15).

TABLE 3

Mean weld metal, HAZ, base metal molten and filler metal molten area measurements in two-pass T-fillet joints with different thicknesses

| T-fillet Joint Sample | | Weld Metal Area [mm ²] | HAZ Area [mm ²] | Base Metal Molten Area [mm ²] | Filler Metal Molten Area [mm ²] |
|-----------------------|---|------------------------------------|-----------------------------|---|---|
| 6 mm | 40%Ar-60%CO ₂ | 34.74 | 13.98 | 15.37 | 19.37 |
| | DMAG – 6 L min ⁻¹ Ar – 9 L min ⁻¹ CO ₂ | 33.14 | 16.49 | 13.23 | 19.91 |
| 8 mm | 50%Ar-50%CO ₂ | 41.39 | 17.40 | 17.13 | 24.26 |
| | DMAG – 7.5 L min ⁻¹ Ar – 7.5 L min ⁻¹ CO ₂ | 35.07 | 18.59 | 7.37 | 27.70 |
| 10 mm | 60%Ar-40%CO ₂ | 57.70 | 33.55 | 21.20 | 36.50 |
| | DMAG – 9 L min ⁻¹ Ar – 6 L min ⁻¹ CO ₂ | 58.06 | 30.80 | 20.23 | 37.83 |

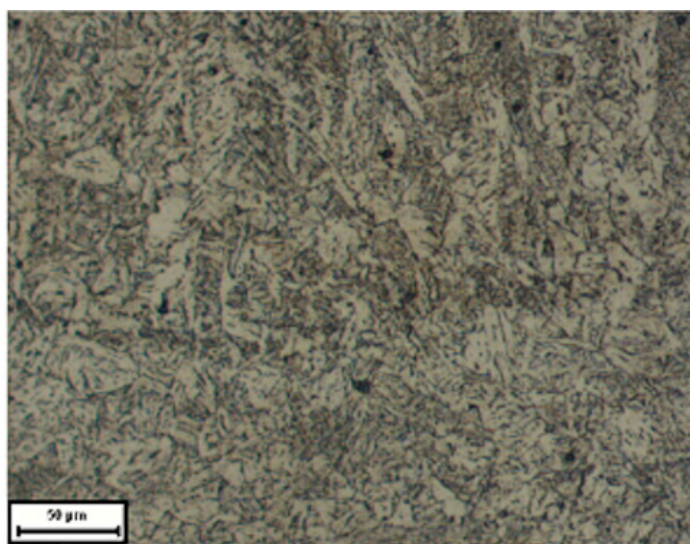
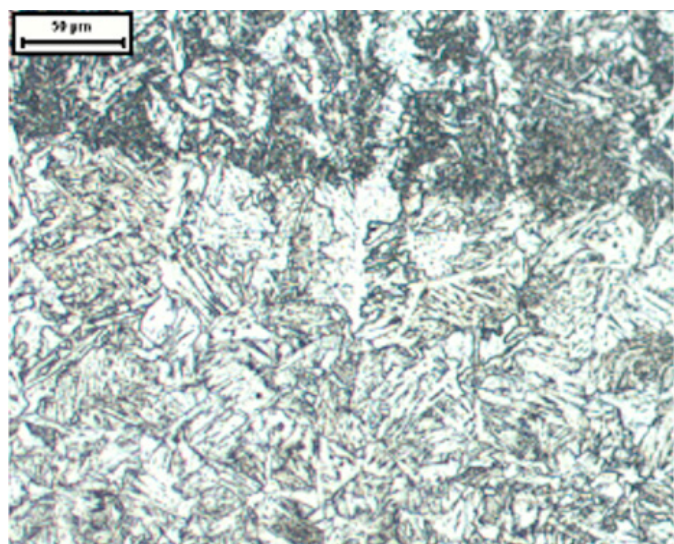


Fig. 11. HAZ micrographs (200×) of DMAG – 6 L min⁻¹ Ar – 9 L min⁻¹ CO₂ (left) and 40%Ar-60%CO₂ (right)

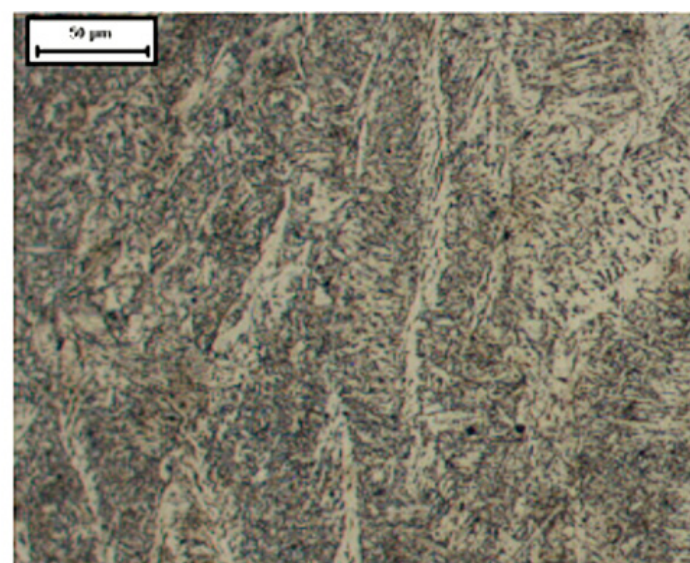
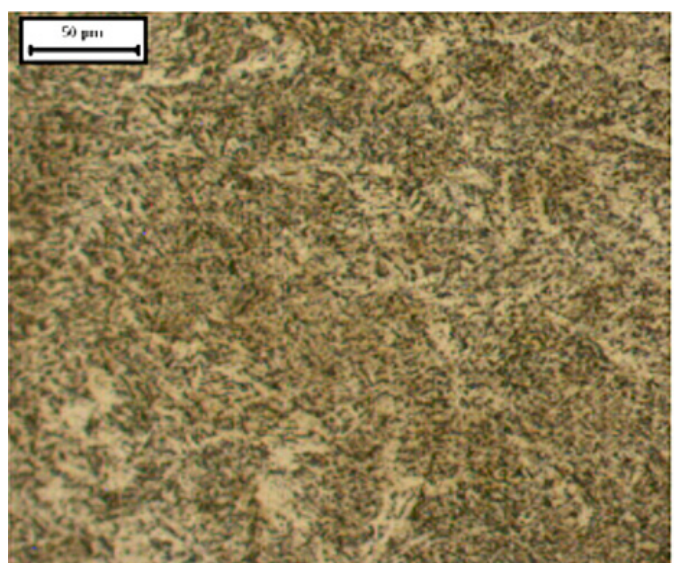


Fig. 12. Weld metal micrographs (200×) of DMAG – 6 L min⁻¹ Ar – 9 L min⁻¹ CO₂ (left) and 40%Ar-60%CO₂ (right)

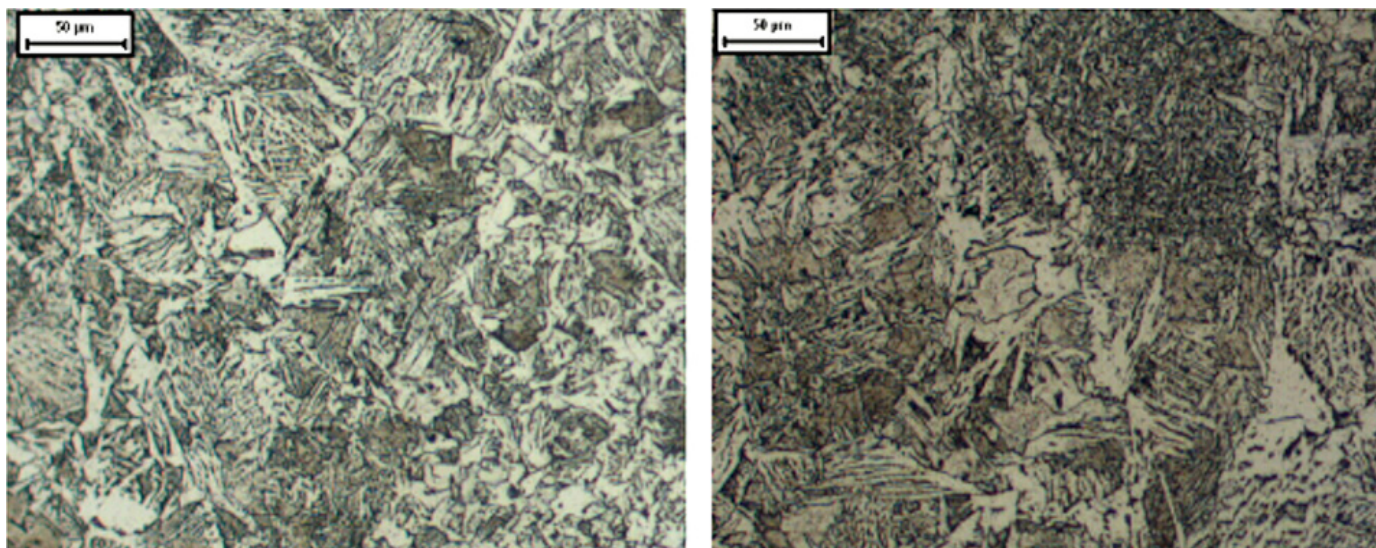


Fig. 13. HAZ micrographs (200 \times) of DMAG – 7.5 L min⁻¹ Ar – 7.5 L min⁻¹ CO₂ (left) and 50%Ar-50%CO₂ (right)

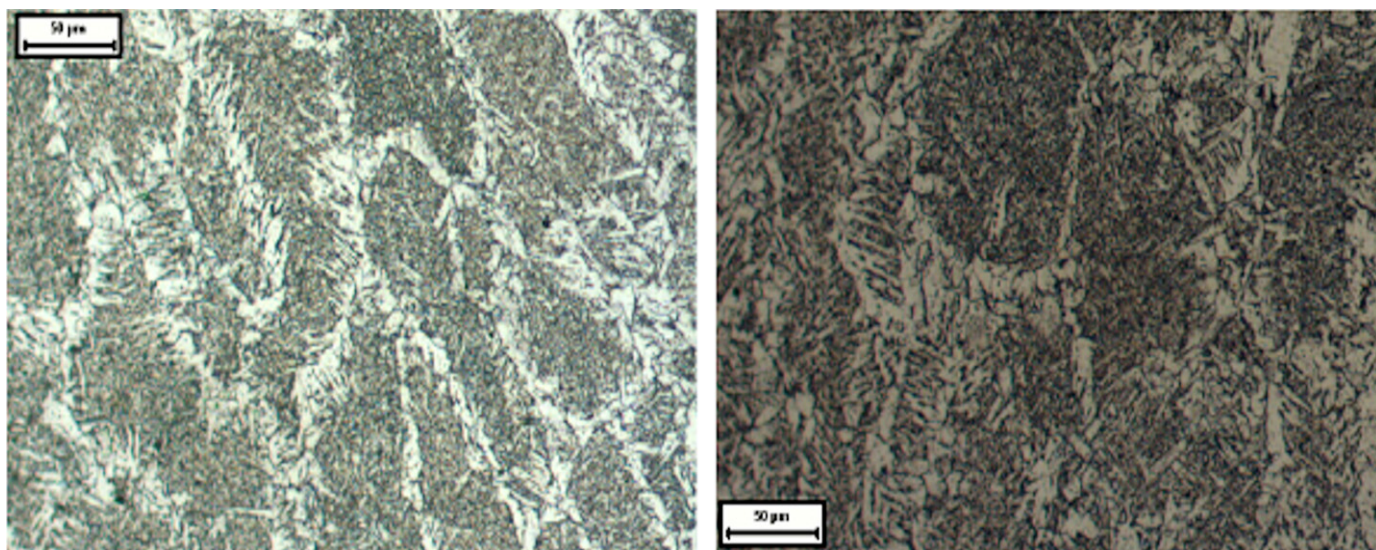


Fig. 14. Weld metal micrographs (200 \times) of DMAG – 7.5 L min⁻¹ Ar – 7.5 L min⁻¹ CO₂ (left) and 50%Ar-50%CO₂ (right)

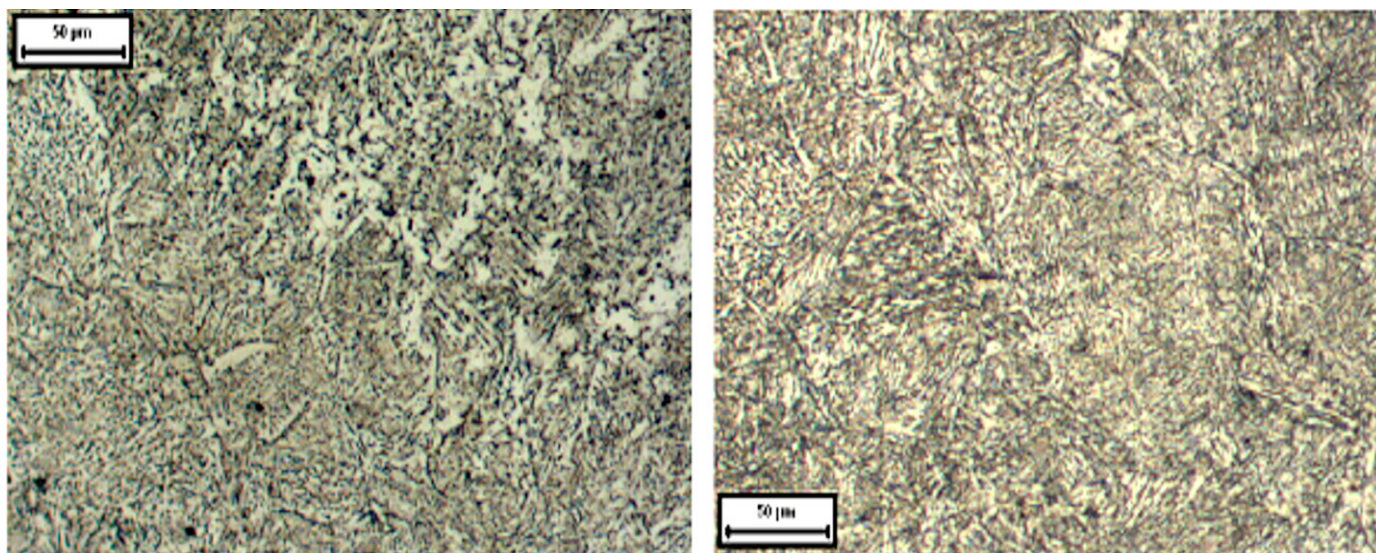


Fig. 15. HAZ micrographs (200 \times) of DMAG – 9 L min⁻¹ Ar – 6 L min⁻¹ CO₂ (left) and 60%Ar-40%CO₂ (right)

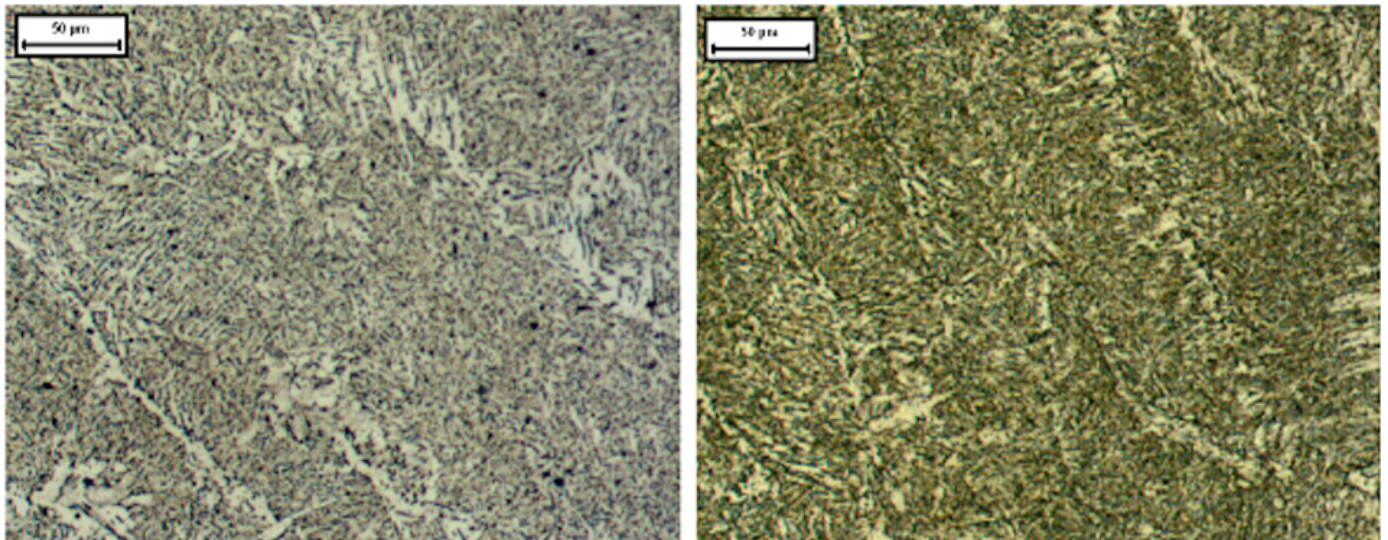


Fig. 16. Weld metal micrographs (200×) of DMAG – 9 L min⁻¹ Ar – 6 L min⁻¹ CO₂ (left) and 60%Ar-40%CO₂ (right)

4. Conclusions

Conclusions drawn from this study can be summarized as follows;

1. When filler metal molten area increased, base metal molten area decreased in DMAG of low carbon steel (Table 3). This provides welding of low carbon steels using DMAG method with higher speeds. Thus, especially in T-fillet welding with DMAG would allow rise in welding speed with regard to weld bead geometry desired in standards.
2. Finer and more homogenous grains observed with DMAG. This result is parallel with the hardness values. Although micrographs of weld beads and HAZs of the welds obtained with the use of both methods involve differences, since carbon content of the base metal is low (~ 0.1 %), there are no significant discrepancies in hardness distributions.

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