Effect of alternating shielding gases in gas metal arc welding of SA515 Gr 70 carbon steel

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Abstract

The influence of alternating shielding gas on fusion characteristics and weld metal characteristics was examined using a solid wire electrode on SA515Gr 70 carbon steel (ER70S). To improve the efficiency of the traditional GMAW process, two shielding gases of Argon and CO₂ were supplied independently to the GMAW torch using a gas alternator unit with a predetermined frequency to the weld area. The weld quality was found to be improved by the periodic variation of the arc. The weld pool dynamics got refined by the enhanced thermo physical properties driven by the alternating shielding gases. Based on the results of the bead on plate welding trial, optimal welding conditions were chosen to construct a single V groove butt-joint weld to characterize its strength and toughness. The alternating shielding gases delivered excellent outcomes in terms of weld bead geometry and mechanical properties in this investigation.

1. Introduction

Due to its numerous advantages, GMAW enjoys a significant honor among arc welding processes. Shielding is the process of replacing a reactive environment (oxidizing, flammable, explosive) or just ambient air with an inert gas. The use of shielding gas is essential for GMAW functioning. Instead of the conventional approach of premixed shielding gas, two different shielding gases (Argon and CO₂) are provided independently at the weld zone [1]. Its goal is to provide a better approach to shield the molten weld pool, resulting in increased weld quality and efficiency [2]. The alternating shielding gases generate periodically varying weld-pool dynamics, which increase weld quality. Regarding non-ferrous applications, the shielding gas is usually argon or a combination of argon and helium. However, a variety of gas combinations containing argon, helium, CO₂, and O₂ are utilized in various industries for steel welding [3]. In Indian businesses, a binary gas mixture with an 80%Ar+20%CO₂ mixing ratio is usual, however alternative combinations such as 95% Ar + 5% CO₂ are also employed [4]. There are three metal transfer modes in the GMAW process: Mode 1: Short-circuiting refers to the process’s lowest range of welding currents and electrode diameter. When the wire comes into contact with the weld metal, the current rises, and the liquid metal at the wire tip is pinched off, causing an arc to form. The shielding gas has relatively little effect on the transfer itself in this form of transmission. The gas, on the other hand, has an effect on the arc’s working properties and base metal penetration. When opposed to inert gases, CO₂ gas produces a lot of spatter, but it allows for deeper penetration when welding steels [5]. Mode 2: Globular transfer refers to the transfer of weld metal across the arc in huge droplets that are typically larger than the diameter of the electrode in use. Regardless of the type of shielding gas used, the current density is minimal. This form of transfer occurs at all welding currents when CO₂ or inert gases are used [6]. Mode 3: Spray transfer is exceptionally stable and devoid of splatter. It uses a relatively high voltage and wire feed speeds or amperage and is smaller than the diameter of the wire. Pre-mixed argon shielding gases have become a need for spray transfer modes in GMAW. Other transfer uses the pure argon premixed shielding gas to decrease spatter loss and...
improve the aesthetics of GMAW welds. GMAW has not developed alternating shielding gases as a technique of reducing gas use. Instead, it’s created as a scientific way to affect weld pool dynamics and improve shielding efficiency as well as the metallurgical and mechanical properties of the weld metal. With an increase in welding current, the depth of penetration increases linearly. Voltage showed the same trend but with lesser magnitude. The effect of welding current on penetration was found to be 2.5 times greater than voltage and welding speed. A result, alternating the introduction of Argon and CO₂ gases into the arc at a predetermined frequency causes the operating point to shift from one to the other at the same rate as the two shielding gases. Due to the impact of Argon and CO₂ gases, the operating point varies; the transfer mode also changes regularly from short-circuiting to spray and vice versa. The factors affecting the selection of appropriate carbon steel electrode was studied. The effect of alternating the shielding gases namely argon and helium in welding of aluminium resulted in lesser porosity and better penetration. It was feasible to boost the strength properties of the new method by combining the advantages of argon-arc and helium-arc welding. Lowest degree of welding distortion was achieved in austenitic stainless steel welding by argon +67% helium mixture. The parameters influencing the selection of suitable shielding gases were studied. The standard testing methods to qualify the welded joints were analyzed. In GMAW fume generation rate is dependent on welding current. The frequency and diameter of the transferred drops, as well as the process stability, are affected by the value of the globular spray transition current. This experimental study aims to examine the effect of alternating shielding gas in metallurgical, mechanical, and chemical properties of GMA welded SA515 Gr70 carbon steel, which is predominantly used in high-pressure boiler.

2. Materials and methods

Using the Lincoln Power Wave 455 power source, a series of welding studies were done on SA515Gr70 carbon steel material with 1.2 mm diameter carbon steel consumable electrode wire complying to ER70S-6 (AWS A5.18). Typical chemical composition and Mechanical Properties of base metal and electrode wire are given below in the following tables 1 and 2. The experimental setup is shown in figure 1. Shielding gas comprising of...
CO₂ and Argon was supplied separately to the GMAW torch using the gas alternator unit developed by the Welding Research Institute (WRI), Bharat Heavy Electricals Limited (BHEL) India. A solenoid valve, controlled by a timer, changes the shielding gas on a regular basis. The shielding gas alternator has two timer knobs that control the predetermined frequency of each gas. The gas alternator is equipped with two different gases from two individual gas cylinders which is meant for the GMAW torch. It not only solves the limits of the mixed gas method, but it also has an impact on all aspects of arc welding. Aside from the wire feed speed, current and voltage parameters, the shielding gas employed in the GMAW process has a solid impact on the operating point. The stable operating point for each shielding gas, namely Argon and CO₂, is positioned in the parametric window differently. As a result, alternating the delivery of Argon and CO₂ gases into the arc at a predetermined frequency causes the operating point to change from one to the other at the same frequency. Due to the impact of argon and CO₂ gases, not only is the operating point changed, but the mechanism of transfer also varies regularly from short-circuiting to spray and vice versa. The weld pool dynamics, as well as the resultant weld bead shape, penetration, and weld metal characteristics, are all influenced by these two processes. The heat input and arc efficiency of alternating shielding gas were measured using an arc data monitor from the Welding Research Institute. Every second during welding, the arc data monitor was utilized to measure the arc stability of welding current and arc voltage for each bead on plate trial. The arc current and arc voltage was measured, and the actual heat input was calculated.

This research is done in two parts. The effects of alternating shielding gas and 100% CO₂ shielding gas on arc stability, depth of penetration, deposition rate, microstructural characteristics, and hardness distribution of deposited weld metals were studied in the first stage by bead on plate welding trials with plate dimensions of 150 (l) × 150(w) × 10 (t) mm and welding parameters listed in table 3. The experimental plates were checked for soundness using visual inspection and X-ray diffraction testing. Weld beads were cut for macro specimens enabling for ASME-standard weld bead geometry calculations. Tables 4 to 7 show the measured values of depth of penetration, bead height, bead width, and plate fusion area using the profile projector. Based on the findings of the bead on plate welding trial, the best welding parameters were chosen. For the second stage, complete weld joints were achieved by mechanically beveling two plates with dimensions of 500 (l) × 150 (w) × 20 (t) mm each to construct a single V groove butt-joint with a 12 mm root gap opening. 1.32 kJ mm⁻¹ is the heat input. In order to keep the inter pass temperature at 150 °C, a single V groove butt-joint with multi-pass welding was performed in a flat position. The welding settings were as follows: 100% CO₂ shielding gas, alternating shielding gas (with a gas pulse duration of 1 s), and the welding parameters as listed in table 8. All weld tensile tests, Charpy impact tests, side bend tests, and metallographic examinations were performed on the single V groove butt joints weld. All weld tensile specimens were obtained parallel to the weld direction with dimensions of 13.10 (Ø) × 180 (l) mm, as per AWS B 4.0 Cylindrical. Also, for this test, Square side bend specimens with dimensions of 200 (l) × 20 (w) × 10 (t) mm and a mandrel diameter of 4 T for the bend angle of 180° are used to evaluate the weld metal properties. The fusion and heat-affected zones were identified using metallographic and microstructural techniques. The macro images were imported to imaging software, Image J. The same software was used to measure the weld bead geometries namely, depth of penetration, bead height, bead width, included angle, area of penetration and deposition. For each and every measurement five readings were taken and the average values were reported in order to take care of the precision of the measured values.

### 3. Result and discussion

The weld bead was critical in determining the weld’s mechanical properties. The effect of weld bead geometry on alternating shielding gases and traditional GMAW, bead-on-plate welding trials was explored. Figures 2 and 3 demonstrate the weld bead for the short circuit mode and spraying mode of transfer using the alternating...
Table 4. Data of Bead geometry for bead on plates of welding trail—1.

| Welding parameters                  | Gas time (s) | Depth of penetration, d (mm) | Bead height, h (mm) | Bead width, W (mm) | Angle, θ° | Area of penetration, Ap (mm²) | Area of deposition, Ad (mm²) |
|-------------------------------------|--------------|------------------------------|---------------------|--------------------|-----------|-------------------------------|-----------------------------|
| Current I: 100 A,                   | 1.0          | 1.2 ± 0.2                    | 2.4 ± 0.1           | 6.0 ± 0.2          | 50 ± 1    | 9.93                          | 3.72                        |
| Voltage V: 18 V,                    | 1.5          | 1.3 ± 0.1                    | 2.6 ± 0.2           | 6.0 ± 0.2          | 50 ± 1    | 10.95                         | 3.46                        |
| Standoff distance SoD: 12 mm,       | 2.0          | 1.4 ± 0.1                    | 2.7 ± 0.1           | 6.1 ± 0.1          | 50 ± 1    | 9.45                          | 4.12                        |
| Wire Feed Rate WFR: 2.36 m min⁻¹,  | 2.5          | 1.4 ± 0.1                    | 2.8 ± 0.2           | 6.2 ± 0.1          | 50 ± 1    | 11.74                         | 4.32                        |
| Welding Speed                       | 3.0          | 1.6 ± 0.1                    | 2.8 ± 0.2           | 6.2 ± 0.2          | 49 ± 1    | 11.12                         | 4.18                        |
| W S: 250 mm min⁻¹, 100% CO₂          | 1.6 ± 0.2    | 2.6 ± 0.2                    | 6.4 ± 0.2           | 48 ± 1             |           | 9.52                          | 4.69                        |
Table 5. Data of Bead geometry for Bead on Plates of Welding Trail - 2.

| Welding Parameters | Gas Time (s) | Depth of penetration, d (mm) | Bead Height, h (mm) | Bead Width, W (mm) | Angle, $\theta^\circ$ | Area of Penetration, $Ap$ (mm$^2$) | Area of Deposition, $Ad$ (mm$^2$) |
|--------------------|--------------|------------------------------|---------------------|-------------------|---------------------|-----------------------------------|----------------------------------|
| Current I: 200 A,  | 1.0          | 2.6 ± 0.2                    | 3.6 ± 0.2           | 11.2 ± 0.2        | 55 ± 1              | 28.42                             | 20.21                            |
| Voltage V: 24 V,   | 1.5          | 2.8 ± 0.2                    | 3.5 ± 0.2           | 10.8 ± 0.1        | 55 ± 1              | 28.24                             | 20.13                            |
| Standoff distance SoD: 14 mm, | 2.0          | 2.7 ± 0.1                    | 3.4 ± 0.1           | 11.1 ± 0.1        | 55 ± 1              | 29.23                             | 20.31                            |
| Wire Feed Rate WFR: 6.52 m min$^{-1}$ | 2.5          | 3.0 ± 0.1                    | 3.6 ± 0.2           | 10.7 ± 0.2        | 55 ± 1              | 28.83                             | 21.05                            |
| Welding Speed W: 250 mm min$^{-1}$ | 3.0          | 2.8 ± 0.1                    | 3.4 ± 0.2           | 10.4 ± 0.2        | 54 ± 1              | 28.12                             | 22.04                            |
| 100% CO₂            | 3.2 ± 0.2    | 3.3 ± 0.2                    | 10.5 ± 0.2          | 52 ± 1            | 27.45                             | 21.27                            |
Table 6. Data of bead geometry for bead on plates of welding trail—3.

| Welding parameters | Gas time (s) | Depth of penetration, d (mm) | Bead height, h (mm) | Bead width, W (mm) | Angle, θ° | Area of penetration, Ap (mm²) | Area of deposition, Ad (mm²) |
|--------------------|-------------|-------------------------------|---------------------|-------------------|----------|------------------------------|----------------------------|
| Current I: 250 A,  | 1.0         | 3.6 ± 0.2                     | 4.0 ± 0.2           | 13.0 ± 0.2        | 58 ± 1   | 35.12                        | 23.91                      |
| Voltage v: 26 v,   | 1.5         | 3.5 ± 0.2                     | 4.2 ± 0.2           | 12.8 ± 0.1        | 57 ± 1   | 35.32                        | 23.67                      |
| Standoff distance SoD: 16 mm, | 2.0         | 3.3 ± 0.1                     | 4.3 ± 0.1           | 13.2 ± 0.1        | 56 ± 1   | 34.37                        | 22.63                      |
| Wire Feed Rate WFR: 9.92 m min⁻¹ | 2.5         | 3.4 ± 0.1                     | 4.2 ± 0.2           | 12.4 ± 0.1        | 59 ± 1   | 33.81                        | 22.42                      |
| Welding Speed W S: 300 mm min⁻¹ | 3.0         | 3.4 ± 0.1                     | 4.3 ± 0.2           | 12.5 ± 0.2        | 55 ± 1   | 35.66                        | 23.75                      |
| 100% CO₂           | 3.6 ± 0.2   | 4.2 ± 0.2                     | 13.0 ± 0.2          | 56 ± 1            |          | 37.59                        | 22.85                      |
### Table 7. Data of Bead geometry for Bead on Plates of Welding Trail—4.

| Welding Parameters            | Gas time (s) | Depth of penetration, d (mm) | Bead height, h (mm) | Bead width, W (mm) | Angle, $\theta$ | Area of penetration, Ap (mm$^2$) | Area of deposition, Ad (mm$^2$) |
|-----------------------------|--------------|-----------------------------|---------------------|-------------------|----------------|----------------------------------|---------------------------------|
| **Current I: 290 A,**       | 1.0          | 4.0 ± 0.2                   | 5.0 ± 0.2           | 13.6 ± 0.2        | 62 ± 1         | 50.34                            | 34.23                           |
| **Voltage v: 28 v,**        | 1.5          | 4.1 ± 0.2                   | 4.8 ± 0.2           | 14.0 ± 0.1        | 61 ± 1         | 51.77                            | 33.77                           |
| **Standoff distance SoD: 18 mm,** | 2.0          | 4.2 ± 0.1                   | 4.9 ± 0.1           | 13.7 ± 0.1        | 60 ± 1         | 51.09                            | 32.38                           |
| **Wire Feed Rate WFR:11.2 m min$^{-1}$,** | 2.5          | 4.0 ± 0.1                   | 5.0 ± 0.2           | 14.0 ± 0.2        | 60 ± 1         | 50.28                            | 31.95                           |
| **Welding Speed W:300 mm min$^{-1}$,** | 3.0          | 4.0 ± 0.1                   | 4.6 ± 0.2           | 14.1 ± 0.2        | 61 ± 1         | 51.11                            | 31.29                           |
| **100% CO$_2$**              | 3.8 ± 0.2    | 4.7 ± 0.2                   | 14.1 ± 0.2          | 61 ± 1            |                | 51.69                            | 32.88                           |
shielding gas method, respectively. In analyzing the weld joint properties, the bead profile, which included bead width, reinforcing height, depth of penetration, and fusion zone area, was critical. The size of the weld bead is determined by a variety of welding process factors, including current (A), voltage (V), filler wire feed rate (m/min), welding speed (m/min), standoff distance (SoD in mm) and alternating shielding gas pulse frequency time interval (GPF in seconds). The factors were interrelated, and changing one might have an impact.
Table 8. Single V groove butt-joints were conducted by the optimize welding parameters.

| Various parameters                  | Parameter range |
|-------------------------------------|----------------|
| Current (A)                         | 290 A          |
| Voltage (V)                         | 28 V           |
| Welding Speed (WS)                  | 300 mm min⁻¹   |
| Standoff Distance (SoD)             | 18 mm          |
| Wire Feed Rate (WFR)                | 11.2 m min⁻¹   |
| Gas pulsing Frequency (GPF) for Alternating shielding gases (Argon and CO₂) | 1 s         |

on the others. As a result, it appears that understanding the link between process parameters and bead dimensions, as well as exercising control over these variables in order to optimize process parameters, is critical.

Shielding gases have various physical and chemical properties, such as ionization energy, thermal conductivity, and chemical activity, which affect arc behavior and, as a result, the weld bead profiles. The effect of alternating gas pulsing frequency of shielding gases viz CO₂ and Argon on the aforesaid aspects of the weld beads in ‘Alternating shielding gases of GMAW’ has been researched and compared to that of the weld beads deposited with 100% CO₂. The shape of the weld bead indicated a bead geometry that was determined by the load-carrying capacity of the weldments and the number of passes required to fill the single V groove butt-joint. The outcomes are shown in the table below.

3.1. Weld bead surface characteristics
The surface characteristics of weld beads deposited with conventional GMAW short-circuiting and spray modes of transfers were researched and compared to those of weld beads deposited with ‘Alternating gases GMAW.’ The duration of gas pulsing examined ranged from 1.0 to 3.0 s. The bead surface profiles obtained in short circuit mode are shown in figure 2. Beads B1 to B5 were deposited using ‘Alternating gases GMAW’ with increasing gas pulse lengths, while bead ‘A’ was formed using a 100% CO₂ shielding gas. Argon with its 1.784 g l⁻¹ density as well as 1.4 times heavier than air exhibits the effective shielding and blanketing the weld pool as an inert shielding gas. CO₂ with its 1.977 g l⁻¹ density reacts chemically with the weld pool, changing the weld metal’s mechanical and chemical properties as a reactive shielding gas. A distinguishing aspect of ‘Alternating gases GMAW’ welds is the appearance of rippled and shining surfaces that alternate with the bead. The ripples appear to emerge purely as a result of the weld pool oscillating during solidification in GMAW [20]. The ripple causing oscillations were attributed due to the change in densities of the shielding gases namely Argon and CO₂. CO₂ shielding was presented by the rippling segments of the bead, whereas argon shielding was represented by the glossy regions denoted by arrow heads. The pattern alternatively reoccurs in equal intervals of length. The ripple and shiny surfaces appear along the weld length because CO₂ and argon are supplied alternately in this process. On the one hand, CO₂ addresses the issue of deep weld penetration, while Argon ensures excellent blanketing and oxidation resistance. In the process of alternating the shielding gases, a synergistic effect was produced. Low gas pulse lengths, such as 1 s, overlap significantly resulting in a homogenous bead formation.

More noticeable discrete segments of ripple and shining patches are observed along the weld length with longer gas pulse duration, i.e. 3.0 s. Because of the greater welding speed involved in the GMAW process, the gas pulsing period in ‘Alternating gas GMAW’ should be 1 s for obtaining a homogeneous bead profile. Figure 3 depicts the effect of gas pulsing frequency on weld beads deposited in the spray mode of transfer in ‘Alternating Gas GMAW.’ Weld beads numbered B1 to B5 are deposited using ‘Alternating gases GMAW’ with increasing gas pulse duration, while weld beads numbered ‘A’ are deposited using 100% CO₂ shielding gases. It’s worth noting that the ripple and shine segments have homogenized in the spray mode of transfer due to the overlapping of gas effects in a big weld pool. As a result, even longer gas pulse durations, such as 3.0 s, do not form distinct ripple and shining segments along the weld like they do in the short-circuiting transfer.

3.2. Depth of penetration
By sectioning the weld beads in transverse and longitudinal (along with the weld length) directions, the effect of frequency of in alternating gases GMAW on the penetration profile was investigated. The effect of gas pulsing was seen in the longitudinal penetration profile, which shows a periodically shifting penetration profile over the weld length. In weldments involving short circuit mode, the penetration profile vary with the frequency of the gas pulsing. Figures 4(A) and (B1) show 100% CO₂ weldment and alternating shielding gas weldment macrostructure, respectively in short circuit mode. They exhibited more over same depth of penetration. The penetration profile of typical macrographs along the weld length is also fairly uniform and even. Figures 5(A) and (B1) show 100% CO₂ weldment and alternating shielding gas weldment macrostructure, respectively in spray...
mode of transfer. The depth of penetration was found to be considerably higher for the alternating shielding gases.

Increased welding current increases heat input, which increases the amount of molten base welding current, voltage parameters, and spray metal, resulting in increased penetration depth. The welding current rises from 100 to 290 A, and the depth of penetration rises from 1.2 to 4.2 mm. Due to the potential ionization difference between pure argon and pure CO2, the quantity of generated heat input is influenced by alternating shielding gas. Due to the temperature distribution, it was also discovered that stable pulse frequency argon and CO2 shielding gas supply created a weld with deep penetration and lower spatter rate. CO2 being a reactive shielding gas contributed for the deeper penetration.

3.3. Reinforcement height
The wetting behaviour of the weld metal is shown by the reinforcing height. Wetting behaviour is improved when GMAW weld beads are deposited with alternate shielding gas rather than 100% CO2. The height of reinforcement for alternating shielding gases GMAW was determined to be the same as that of 100% CO2. At all pulsating gas frequencies, the welding current increases from 100 to 290 A, and the reinforcement height increases as the flow increases.
Figure 6. (a)–(d) Oscillograms of welding current and arc voltage in short circuit mode of transfer.
3.4. Weld pool area

The rate of heat input was increased by alternating shielding gases, resulting in a huge weld pool in the fusion area. The percentage of dilution in the weld region and the plate fusion area are used to measure the quality of

Figure 7. (a)–(d) Oscillograms of welding current and arc voltage in spray mode of transfer.
welded joints. Under short-circuiting and Spray mode of transfer welding conditions, the plate fusion area is the same for both conventional and alternating shielding gas. The deposited metal area is almost same. However, in GMAW it was discovered that the alternating shielding gases exhibited slightly superior bead-wetting behaviour than conventional approaches.

3.5. Arc stability
Figure 6 shows the welding current and voltage [I-V] of transient waveforms with 100% CO₂ and alternating shielding gas. The amount of spikes in the voltage waveform indicated that the wire tip is frequently electrically short-circuited with the weld pool. At the same time, as shown in figure 6, alternating shielding gas waveforms arise in sequence depending on the pulsing gas frequency. To view the I-V transient in spray mode, the segments corresponding to the argon gas flow have a stable current and voltage waveform, while the portions corresponding to the CO₂ gas flow have a number of spikes marking the onset of the short-circuiting transfer.

In the voltage waveform, it corresponds to 100% CO₂ number of spikes, indicating the occurrence of short-circuiting transfer. Unlike GMA welding, which uses alternate shielding gases; these two waveforms appear in sequence dependent on the pulse gas frequency, as shown in figure 7.

3.6. Microstructure of the weld metal
The microstructures of base metal, Heat Affected Zone (HAZ), and weld metal utilizing alternate shielding gases were compared to the traditional GMAW process using an optical microscope.

Changing the welding current and hence the quantity of heat input created varied temperature distributions in the weld and parent metal during the heating and cooling cycles. As shown in figure 8, the Macro and Microstructures of the weld metals are created by alternating shielding gas and 100% CO₂. Figure 8 depicts the metal microstructure of large-area acicular ferrite and pearlite welds. At the same time, a huge patch of acicular ferrite was discovered in the alternating gas. The microstructures showed both dendritic and lathy ferrite morphologies. The pearlitic solidification of CO₂ shielding gas yielded dendritic shape. The disintegration of ferrite during the cooling of argon shielding gas produces a lathy ferrite. It was discovered that the microstructures are dendritic in character, with dendrites becoming coarser as the shielding gas alternates.

Figure 8. Macro and Micrograph of the single V groove weld joints.
3.7. Inclusion of the weld metal
The inclusion content of weld metal deposited with solid wires and the typical inclusions were examined with 100% CO₂ and alternating shielding gases, as illustrated in figure 9. 100% CO₂ shielding gas showed a high inclusion content, while alternate shielding gases displayed lower inclusion content. Due to the greater weld metal oxygen concentration, high-temperature transformation products such as allotriomorphic ferrite and widmanstätten ferrite were discovered in weld metal deposited with 100% CO₂ shielding gas. For a significant volume of fraction oxide productive inclusion, a large number of tiny inclusions (less than 0.2 μm) causes austenite grain size to decrease and grain border area to grow. Grain boundary ferrite and certain acicular ferrite are produced by austenite grains. More acicular ferrite, widmanstatten ferrite, and less grain boundary ferrite were detected in the weld metals deposited for alternate shielding gas. The size and distribution of acicular ferrite nucleates on oxide inclusions with sizes ranging from 0.2 to 2 μm are shown in this micrograph. Fine acicular ferrite produced in the weld as a result of the alternate shielding gas pulses.

3.8. Tensile tests
The main goal is to assess the performance of the welding joint in terms of strength and plasticity. The yield strength and ultimate tensile strength of weld metal deposited under alternating gases of Argon and CO₂ was found to be 487 ± 7 MPa and 594 ± 4 MPa, respectively. Whereas, the yield strength and ultimate tensile strength of 100% CO₂ shielding gas deployed GMAW was found to be 467 ± 6 MPa and 551 ± 5 MPa, respectively. However, the percentage reduction in area of alternating shielding gases weldments are marginally greater (70 ± 2)% than the 100% CO₂ shielding gas weldments (68 ± 3)%. The percentage of elongation also shows the same trend, viz (35 ± 3)% for alternating shielding gases and (33 ± 2)% for 100% CO₂ weldments. The yield and ultimate tensile strength values were higher for GMAW with alternating shielding gases. The flexibility indicated by percentage elongation and percentage reduction in the region, on the other hand, was slightly lower. The lower loss of Si and Mn during the deoxidation process is responsible for the enhanced strength with alternate shielding gases GMAW. Furthermore, as seen by the decreased inclusion content in alternate shielding gas GMAW, the clean weld metal may attribute for the enhancement of the strength.

3.9. Impact tests
Impact tests were performed in alternating shielding gas and 100% CO₂ weldments to evaluate the weld metal’s toughness at room and subzero temperatures. The toughness properties of weld metal deposited with alternating shielding gas are superior to weld metal kept with 100% CO₂ shielding. Figure 10 depicts the weld metal strength values. The small grain size and refined microstructure of the weld metal deposited with alternating shielding gases of Argon and CO₂ attributed to the increased toughness qualities and possessed impact
strength values of \((159 \pm 2)\) J compared to 100% CO\(_2\) weldments \((155 \pm 4)\) J. The size of the grain has a significant impact on the transition temperature. A one-standard-number increase in ferrite grain size (a decrease in grain diameter) might cause a decrease in transition temperature. The transition temperature of the impact specimen is reduced when the grain diameter change is reduced, improving impact resistance. Furthermore, in grain boundary ferrite, cleavage cracks propagate more easily than in acicular ferrite. In the absence of other brittle zones, the acicular ferrite had a good influence on toughness \([20]\). For side bend tests, there were no cracks; the material’s ductility capabilities for alternating shielding gas preserved their elasticity.
4. Conclusion

The fusion characteristics and weld metal properties of SA515Gr70 carbon steel were investigated in this study using alternating shielding gases (argon and CO2) and compared to the traditional GMAW technique (100% CO2 shielding gas). The following are the findings of the aforesaid study:

1. Alternating shielding gases showed a substantial impact on SA515Gr70 carbon steel welds’ arc stability and efficiency, deposition rate, microstructure, chemical, and mechanical properties.

2. Alternating shielding gases displayed no discernible effect on the fusion characteristics of the standard GMAW process. The bead width and plate fusion area values of the alternating shielding gas weldments are more or less same like that of the 100% CO2 weldments.

3. It reduced the spatter level and porosity present in the weld metal, for the input heat differ the shielding gas effect, the deposited metal area exhibited nearly the same, and the wetting characteristics seem to be relatively better.

4. Due to the effect of shielding gas, the heat input was continuously varying, and thereby reducing the amount of spatter and porosity in the weld metal. The deposited metals were seen to be homogenous and the wetting qualities appeared to be relatively improved.

5. The uniformly varying heat input and the formation of a high acicular ferrite structure lead to improve strength of weldments and toughness, respectively.

6. The tensile strength values of alternating shielding gases GMAW weldments was high when compared to 100% CO2. It also exhibits excellent fusion characteristics. Meticulous usage guaranteed a significant cost saving of shielding gas.

7. The higher impact strength obtained was well justified by surfaces showing mixed-mode of ductile fractures and cleavage fractures of the weld surface. When analyzing the ductility property of the alternate shielding gas GMAW weldments by side bend test, no obvious cracks were found.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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