Innovative Cost Effective Concept in GMAW Process to Improve / Enhance Weld Aesthetics, Quality and Fatigue Life

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Introduction

In earth moving industry 80% of the structures are fabricated by semi-automatic welding.

GMAW (MAG) with CO_2 gas as a shielding gas is the cheapest welding process either for Automatic welding or for Manual welding (Semi-automatic). Higher welding speed, better joint penetration and lower costs have led to the extensive use of CO_2. Though CO_2 welding is offering many advantages, **its harsh arc often overshadowed** the process advantages with semi-automatic (manual) welding. With automatic welding where welder's skill doesn't play a role, the process can be used with full efficiency nevertheless of the arc characteristics. The same is not true in case of semi-automatic (manual) welding where a welder must be skillful enough to produce sound weld deposits due to poor stability of the arc and difficulty in controlling the molten weld pool.

The structures in earth moving equipment invariably consist of different joint designs and configurations. A large number of these structures are being welded in Horizontal, Vertical and Overhead positions due to the shape of the job. Skilled welders may produce sound welds irrespective of the constraints like welding position, component shape, welding process etc. However there will be lesser opportunity for an organization to utilize the skilled welder due to the scarcity of skilled personnel where multi level of people are deployed for work in the industry and also welding skill decline sharply with advancement of age of welders. With this situation the organization is forced to utilize an average or below average skilled welder for the production. This often resulted in defective welds having undercuts, excessive spatter and poor bead appearance with manual CO_2 welding. The subsequent rework on the component increases the production cost and time. To overcome this setback an alternate strategy is required which should encompass the CO_2 welding advantage in addition to welder's comfort to deliver quality welds. The possible alternatives may be Automation, Welding Process and Change of shielding gas. Prior to selection of anyone of the above its merits and demerits should be analyzed to suit the requirements.

Automation

In general automation has been utilized in manufacturing processes to minimize the dependence on manual labour and enhance productivity. The other benefits are better weld quality, control over weld size, penetration, better aesthetic look. It ensures better operator safety against heat, emissions, gases and fumes that are created during welding.

However the main limitation is its capital cost. It is mostly suitable for repetitive type of jobs for e.g. resistance spot welding. Automation cannot be replicated for a manual operation, as this is unlikely to be the most efficient or reliable method especially for complex critical joints. It also requires considerable skill for programming (Robot) and manipulation during welding. In earth moving industry where structures are intricate in shape and geometry, automation is not possible in all areas.

Processes Capabilities and Limitations of Other Welding Processes

Shielded Metal Arc Welding (SMAW)

SMAW is most commonly used process in production, maintenance, repair and field construction. The equipment is relatively simple, inexpensive and portable. The process is suitable for wide varieties of materials like carbon steel, low alloy steels, stainless steel, cast irons, Al, Cu, Ni and their alloys. It can be used in areas of limited access to weld. The limitation of the process is its lower deposition rate and productivity than with GMAW. Welders skill required for this process is of highest order. Slag cleaning and overheating of electrode are its other disadvantages.

Flux Cored Arc Welding (FCAW)

This process is same as GMAW process except that FCAW process uses tubular continuous electrode in place of solid wire continuous electrode. This process enjoys the unique feature of dual shielding through in built flux and external shielding gas. The other advantages are higher deposition rates, higher operating factors and higher deposition efficiency comparable to GMAW process.

The major disadvantage of this process is slag cleaning between passes compared to slag-free GMAW process which is an added labour cost. It generates large volumes of welding fumes than any other welding processes.

Gas Tungsten Arc Welding (GTAW)

GTAW is most suitable for joining thin base metals because of excellent control of heat input This process posses certain inherent characteristics like high arc stability, freedom from spatter, precise control of welding parameters and inert gas shielding. This gives excellent quality weld deposit. The process is capable of manual as well as automatic operation and has all position capability.

However the process is slow with lower deposition rates compared with GMAW, FCAW and SAW process. Equipment costs are higher than GMAW. Skill required for welder in case of manual welding is very high.

Submerged Arc Welding (SAW)

The feature that distinguishes SAW from GMAW and other welding processes is the granular flux material fed along the gravity that covers the welding area. The 'quality of welds, the high deposition rates, the deep penetration and the adaptability to automatic operation are some of the advantages of this process.

The process is limited to only flat position and the equipment is bulky with wire feeder, flux hopper and flux recovery units. In addition this process is not suitable for all metals and alloys that include cast iron, austenitic manganese steels, high-carbon tool steels, aluminium and magnesium,

Change of Shielding Gas from CO_2 to Other Gases

Two types of shielding gas, are used in welding depending on the application. They are Reactive gas (CO_2, O_2, H_2, N_2) and Inert gas (Ar, He). Among all CO_2, and Ar (with CO_2 or O_2) are widely used in GMAW process. Usage of Ar and its mixtures, certainly offers many advantages like better arc stability, spray transfer, better control over weld pool etc over CO_2. However the cost of Ar based mixtures is higher than cost of CO_2 shielding gas.

Our detailed investigation of the above factors with respect to inputs like cost, nature of job, type of joint, the materials involved, welding position, welders skill required and outputs like fatigue life, quality, weld bead aesthetics and productivity revealed that Automation, various Welding processes (SMAW, FCAW, GTAW, SAW) are not a replacement for CO_2 welding for improving the weld quality and aesthetics.

Combination CO_2 Welding and Ar Mixtures ($Ar+CO_2+O_2$) Welding

However though Ar based mixtures are costlier than C02 shielding gas it is economically feasible to meet the desired requirements like weld quality , improved fatigue life and aesthetics if both types of gases are used partially in a multipass welding. This method conceived in BEML is a new concept worldwide to extract the advantages of both

CO_2 welding and Ar mixtures welding economically in a single joint with multipass. After a detailed study of various mixtures of Ar, (Ar+ CO_2 + O_2) mixture is considered to use partially over the CO_2 welds for the present study owing to its certain inherent properties and cost. The composition of this mixture is given in Table 1. The advantage of this method is to utilize characteristics like high penetration, high welding speed from low cost C02 welding up to certain no. of passes and good weld bead appearance and without undercut, from (Ar+ CO_2 + O_2) mixtures on cap pass or finish pass in a single weld joint. This method requires a two way gas flow system for partial selection of gas either inbuilt into the GMAW process from two gas cylinders (or central distribution system) or alternatively, changing the gas cylinder each time when it is necessary to use one type of gas at a time. The former system is not deployed/developed any where else in the world so far and the latter is time consuming process.

To overcome this situation a 'Y' connector has been newly designed for our experiment which is integrated into GMAW process system externally to utilize the gas selectively according to the requirements.

Experiments were carried out with this new concept using two gases (CO_2 - initial layers; Ar+ CO_2 +O_2- final layers). The mechanical properties, weld appearance, quality aspects were studied. A cost benefit analysis was studied and the advantages of this method are presented here.

Experimental Work

Design of 'Y' Connector

The 'Y' connector made up of brass is designed and manufactured in house is shown in fig 1.

After fabrication it has been pressure tested and found acceptable as per requirement. One end is connected to CO_2 line and the other end is connected to Ar line. For our experiment CO_2 was supplied through down line from bulk storage tank. Pre mixed Ar mixtures in appropriate ratios was used from separate cylinder. A control ball valve, connected to a lever is provided at the junction, for selection of CO_2 gas or Ar mixtures.

Welding of Test Plates

The base material is a low carbon structural steel approximately equivalent to ASTM A 36. The composition of the same is given in Table 2. The electrode used was AWS-ER 70S6 which is being used in our industry for regular production. The typical chemistry of the wire is given in Table 3. The test plates were made as per AWS-D1.1 Structural Welding Code - Steel, and the weld joint design is shown in fig 2.

Sample 1 (three specimens) was welded by using CO_2 gas with multiple pass. Sample 2 (three specimens) was welded with Ar mixtures and CO_2 gas. For sample 2 (combined weld) initial 3/4th of the joint was welded with CO_2 gas using 'Y' connector by keeping lever B opened (CO_2 side) and lever A closed (Ar side). Final 1/4th of the joint was welded using Ar+ CO_2+ O_2 mixture by positioning the levers in reverse direction i.e. lever B closed and lever A opened. The welding of bead on plate was carried out for both gases to study the quality and aesthetic aspects of the welds.

Mechanical Testing

The specimens for mechanical testing (UTS, VS, %el and Impact) were made from the test plates and tested as per AWS D1.1 Structural Welding Code/ ASTM E 370.

Results and Discussions

In this section the results are analyzed with respect to the outputs and the convincing technical reasons for selective usage of Argon mixtures economically and technically.

Aesthetics and Quality

The surface weld bead geometry for the welded specimens is shown in fig 3. It is observed that with Ar mixtures the weld bead appearance is far superior to its counterpart CO_2 welds. One of the key aspects of Ar mixtures weld is its shiny appearance on the weld surface whereas CO_2 weld appeared dull and erratic. The reason is due to the formation of very thin oxide layer over the surface of the weld from O_2 in Ar mixtures. CO_2 and O_2 gases in Ar mixtures allowed good axially directed spray metal transfer, stabilized arc which resulted in very good bead appearance, very less or nil weld spatters. The presence of O_2 in the mixtures promotes the wetting and flow of the weld metal along the edges of the weld which causes the weld to be nearly flat (less convex) profile with reduced or nil undercut. In contrast the CO_2 welds are with poor weld bead, more spatter, under cuts, due to the inherent harsh arc with globular and non-axial spray transfer. Poor weld metal flow and wettability are other reasons for undercuts with convex weld beads in CO_2 welds. With Ar mixtures, Flat weld bead is obtained which enables improvement in fatigue life compared to highly convex weld beads of CO_2.

The welding speed of Ar mixtures welding is almost comparable to that of CO_2 welding. The penetration of CO_2 weld is deep and wide whereas the Ar mixtures weld is deep at the centre and shallow at the edge which is in finger shape. However this characteristic is not much useful if Ar mixtures are used only on final or finish layers.

Mechanical Testing

The welded samples were tested with Radiography for soundness of welds and found acceptable. The mechanical test results are tabulated and given in Table 4. It is observed that UTS & yield strength of combined welds (CO_2 + Ar mixtures) are on higher side end percentage elongation and impact strength of combined welds are marginally lower than CO_2 welds. The electrode ER 70S6 which contains normally higher level of Mn (1.4-1.80%) and (Si 0.8-1.15%) is designed for CO_2 welding due to its high deoxidation during welding. In this experiment, the electrode is selected with less Mn & Si content but within the specification range to suit for both Ar mixtures and CO_2 welding and to meet the minimum requirements of code. However the trend in these mechanical properties observed for combined welds in this experiment may be due to the transfer of Mn and Si to the Ar mixtures weld due to lower level of oxidation. Despite the values of % elongation and impact in case of combined welds are marginally lower they are meeting the requirements as per code.

Welding on Actual Job

Welding was carried out on BL09H Wheel Loader's Boom, Arm and BE 220 X Excavator's Boom and Arm to study the performance in practical conditions. The photographs of these welds are shown in fig 4. These welds, with Ar mixtures, which are fillet types, also possess the same characteristics of bead on plate experiment.

Cost Analysis

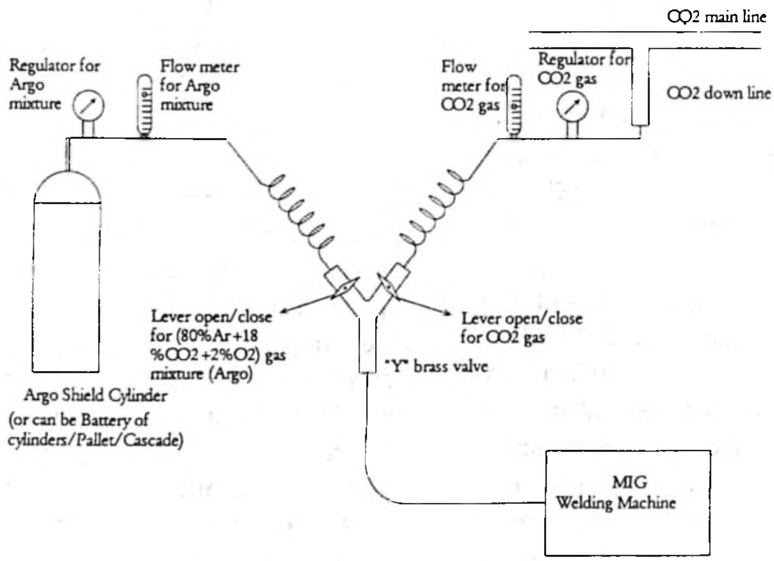
Cost Analysis of GMAW Process Using CO_2 and Ar mixtures as shielding medium is given in table 5.

For our mode of selection, i.e., CO_2 from bulk storage tank and (Ar+ CO_2+ O_2) mixture from cylinder, net difference = 72-68 = Rs.4/kg.

Increase in cost comes to approximately Rs.4/kg (i.e., 5-6% increase in welding cost) of weld deposited, using Argon mixture as shielding medium. Marginal increase in cost eliminates high cost elements, in form of reduced grinding man hours, grinding wheel consumption, grinding machine procurement & maintenance and power.

Conclusions

* Combination of CO_2 welding (initial layers) and Ar mixtures (final layers) can be used successfully in manual (semi-automatic) GMAW process using newly designed 'Y' connector.
* Quality & Aesthetics of Ar mixtures welds are far better than CO_2 welds.
* Weld beads obtained are free from undercuts, having flat/concave weld contours. This improves fatigue life of the members/structures in general.
* Welding cost in case of Ar mixtures is increased marginally but the same gets compensated by eliminating the cost due to grinding (labour, grinding discs, grinding machine, maintenance and power) for rework and removal of spatter.
* Shielding gas envelope through solenoid control valves can be incorporated in the GMAW process system for ease of operation/ usability.



Integrated Brass "Y" connector concepted by Welding Technology Group for improvement of weld aesthetics and fatigue values on BEML equipments

Fig. 1

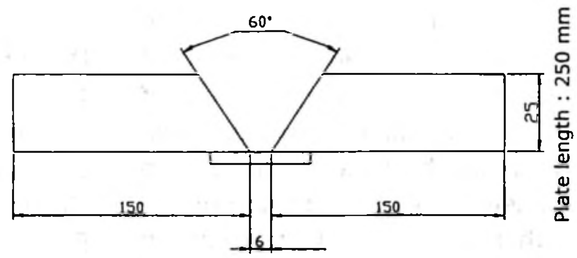


Fig. 2

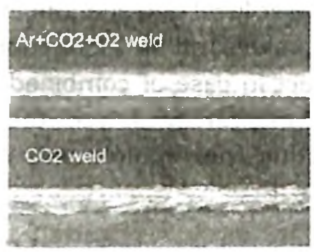
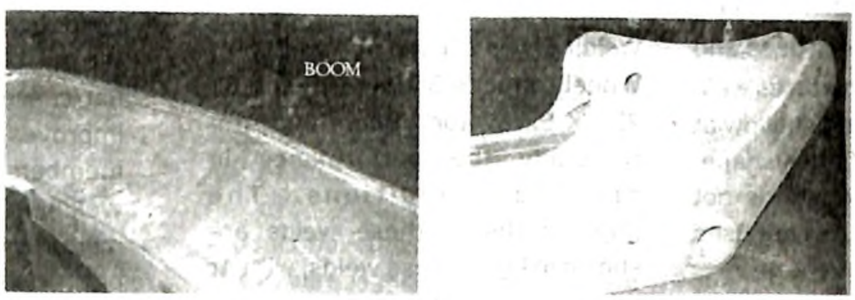
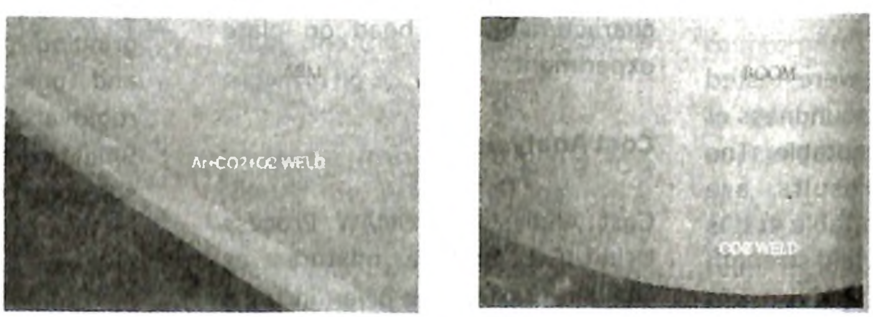


Fig. 3



BL 09H Loader (Ar mixture weld)



BE 220 EXCAVATOR

Fig. 4

Table 1
Composition of Ar mixtures

Ar %	CO_2 %	O_2 %
80	15-18	2-5

Table 2
Base Metal Composition

%C	%Mn	%Si	%S	%P	UTS Mpa	YS Mpa	%EI	Impact energy, J
0.20	0.6	0.9	0.035	0.035	480	270	26	38

Table 3
Electrode Composition

%C	%Mn	%Si	%S	%P
0.12	1.52	0.8	0.019	0.010

Table 4

Welds	**UTS, Mpa**	**YS, Mpa**	**%el**	**Impact energy @ -29°C**
Combined welds (Ar mix + CO_2)	580	465	25	Ave 42 J
CO_2 welds	541	412	30	Ave 46 J

Table 5

GMAW PROCESS

With **CO_2**

Cost of gas from cylinder in Rs./kg = 10.5

Cost of gas from bulk tank in Rs/kg = 7.5

Cost of solid filler wire in Rs/kg = 60

Cost of welding, in Rs/kg

1. When gas is from cylinder
   = 60+10.5=70.5 ≈ 71
2. When gas is from bulk tank
   = 60+7.5=67.5 ≈ 68

With **($Ar+ CO_2+ O_2$) mixture**

Cost of gas from cylinder in Rs./kg = 21

Cost of gas from bulk tank in Rs/kg = 17

Cost of solid filler wire in Rs/kg = 60

Savings due to controlled spatter (metal) loss @ 12.5%, in Rs/kg = 7.5

Savings on power consumption is Rs/kg = 2

Cost of welding, in Rs/kg

1. When gas is from cylinder
   = 60+21-(7.5+2)=71.5 ≈72
2. When gas is from bulk tank
   = 60+17-(7.5+2)=67.5 ≈ 68

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