TRENDS OF WELDING FABRICATION USING CORED WIRES

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1.0 Abstract

Cored Wires usage across various industry segment have shown steady growth over past 20-30 years. This shows versatility of the process and improvement in productivity and related benefit to users. This article describes various welding applications of cored wires like shipbuilding, material handling and earthmoving equipment manufacturing, as well as building of pressure vessels, bridges, complex vessels etc. The article also highlights various welding processes for FCAW like single wire, twin wire and twin tandem welding as well as SAW with cored wires, details of welding consumables and their properties as well as touches upon welding procedures.

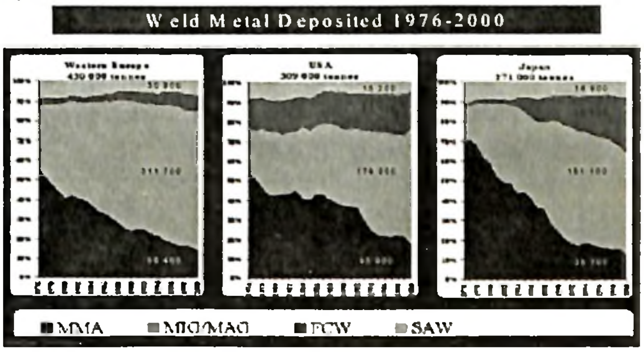
Competitive advantages of Cored Wire welding compared to other processes also has been outlined in detail. New generation metal cored and low fume cored wires as well as cored wires for duplex stainless steel, creep resisting steels also find a mention.

Finally the paper lists out potential for increasing productivity for Indian fabricators by shifting to cored wires. It is pointed out that the productivity increase can be as high as 50% with the help of right welding process and wire, which will mean tremendous cost savings for the company ultimately adding to the operational profitability.

2.0 Introduction

Welding fabricators are generally impressed by cored wires due to the fact that they offer good weldability combined with good mechanical properties and weld quality. Modern cored wires are available with very low diffusible hydrogen content, high resistance to moisture re-absorption coupled with carefully designed flux formulations to yield lower fumes and excellent all positional welding capability. Large increase of productivity when welding with cored wires is a result of higher deposition rate, further complimented by recent development like low diameter metal cored wire as well as packaging innovation. This is well supplemented by reduced risk of fusion defects, lesser spatter and lower sensitivity to porosity when compared to MMA and GMA Welding. Since the introduction of cored wires nearly 5 decades ago, cored wires have increasingly won approval of fabrication segments like shipbuilding and offshore, transportation, light and heavy fabrication and many niche applications. Last decade saw extension of cored wire into high speed

Figure 1



robo welding, advanced materials welding, etc. All these can be attributed to the significant cost benefit accrued when using cored wires over MMA or GMA as well as increasing availability consistent quality cored wires for all position, manufactured by leading producers using advanced manufacturing technique. The rate of growth of consumption of cored wires of carbon, low and high alloy cored wire in the world over has touched double digit in the last few years in most parts of the world, led by nations like USA, South Korea, Japan, etc. (Fig.1) This paper aims to provide information on use of cored wires for a variety of applications. Significant cost benefits also accrue when switching from MMA./GMA welding to cored wire welding.

3.0 Productivity and Quality Aspects

There are two types of cored wires available in the market – Seamless (coppered) and Seamed (non-coppered, either baked or unbaked). Seamless wires are characterized by a relatively low filling ratio of 12-14% compared to Seamed wires with filling ratio of 18-24% (close-butt type) or 30-45% (overlap type). The lower filling ratio of Seamless wires have a negative impact on the productivity of the wire as the current conducting cross section of the wire is bigger. This results in a lower deposition rate compared to equal diameter seamed butt type cored wire, while operating under the same current, gas mixture and welding position – though there is a net increase in the deposition rate compared to solid wires in both cases (Figure 2 & 3).

Cored wires produce a wide arc (axial transfer) resulting in a shallower but a wider form compared to solid wires which tend to produce a pointed metal transfer resulting in fingerform penetration. A slightest misalignment of torch may cause lack of side wall fusion in case of solid wires, but cored wire is much more tolerant to this. The wider arc from cored wires also produce a calm and smooth weld pool, which promotes a regular weld and smooth wash.

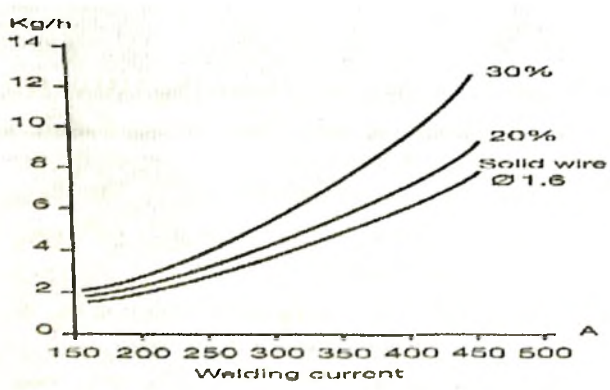


Fig 2. Influence of filling Ratio on deposition rate for 1.6mm dia rutile cored wire

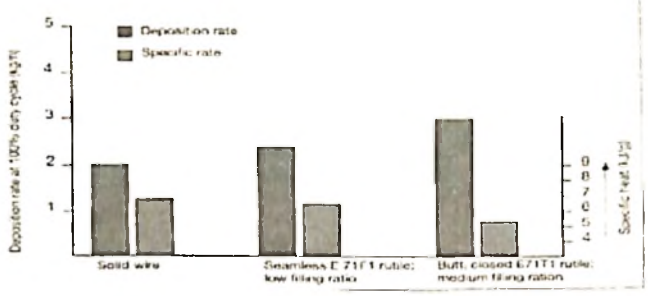


Fig 3. Relationship between deposition rate and specific heat for a solid wire, a low filling ratio cored wire and a medium filling ratio cored wire (all rutile, 1.2mm dia, 180 A, Ar/CO_2 mixed gas)

Lesser spatter is another significant advantage with cored wires, with virtually nil spatters in case of rutile cored wires in spray arc, if welded under mixed gas. Solid wires produce significantly more spatter, especially when welded in dip transfer or globular arc. Metal cored wires have still better operability, specially at higher voltages. With more and more companies paying attention to post-weld cleaning cost reduction, this indeed is a welcome feature.

In addition, high welding speed of cored wires and significant improvement in welder's comfort levels due to improved penetration, smooth tie-in of welds which reduce risk of fatigue cracks in dynamically loaded structure are sound motives for conversion to flux cored wires.

For traditional users of stick electrodes for high-quality fabrication, very low hydrogen welding consumables is a pre-requisite to reduce risk of HIC as well as avoid costly preheat. Obtaining hydrogen levels below 5 ml/100 g is not a problem for most metal cored and basic cored wires, within their full parameter range. However, bulk of all cored wires are rutile type and their hydrogen content is dependent on production technology and associated flux formulation. It is now understood that synthetic arc stabilizers added to facilitate current transfer and arc stability remain hygroscopic, making the wires sensitive to moisture reabsorption in case of drawn seamed wire. This is remedied by producing cored wires using rolling technique which require minimal lubricant and do not require any baking. Such unbaked wires retain their shiny, non-oxidizing appearance and has much lower sensitivity to welding parameter fluctuations and thus producing very low hydrogen weldmetal.

Another significant productivity gain by using one sided welding on ceramic backing support due to use of higher welding current, defect free root and avoiding costly back-gouge is also an added attraction to use cored wires.

4.0 Usage Trends

In conjunction with increased use of C-Steel, Low and High Alloy Steel cored wire across the globe – about 40% process share in USA, 35% in Japan, 20% in Europe and approximately 5% in our own country, a few distinctive trends have been emerging over the recent years. These include small diameter, low fume cored wires, high strength cored wires, metal cored wires and packaging innovation.

4.1 High Strength Cored Wires

It is generally recognized that structures of weld metal often contain a large amount of acicular ferrite. Being a fine grained product, this has a good combination of strength and toughness – a fully acicular C-Mn steel could reach a yield stress of about 560 Mpa in the absence of dispersed titanium [σ = 390 + 1.69 (% acicular ferrite) + 644Ti]. It is emerged from several years of consumables development at ESAB that for strengthening with acicular ferrite, when Ti or other elements are present, sufficient amount of oxygen also to be available to act as a nuclei for ferrite. If the Titanium-oxide is combined with a strong deoxidant M, an equilibrium $TiO2 + 2M = Ti + 2MO$ is set up, with metallic titanium going into solution in the weldmetal. This buffered titanium system is being applied to a variety of tubular wires, first to OK Tubrod 14.53 (the successor to OK Tubrod 14.50, first Ti-B alloyed wire of the world, 1972). This wire is designed for submerged arc welding where good tolerance to heat input and dilution is needed, for eg., on a seam welding of a line pipe. With 1.5% Mn, 2% Ni, 0.3% Mo and Boron addition, the alloying would produce high hardenability in a wrought steel and is sufficient to prevent proeuctoctoid formation even at high temperature. However the large number of nuclei available ensure that acicular ferrite is produced even before any lower transformation products have a chance to form.

In a pipe mill making X 65 pipes, using a 3 wire system at a combined current of 3450 A and a heat input of 7.0 KJ/mm, difficulty had been experienced in achieving CVN impact value of 47 J at –30 0 C with solid wires. When OK Tubrod 14.53 was substituted, using a semi-basic alumina flux, average charpy value rose to 150 J at –30°C and 47 J at –40° C (Fig. 4). Acicular ferrite microstructure welds for strengths upto 600 Mpa is now routinely used.

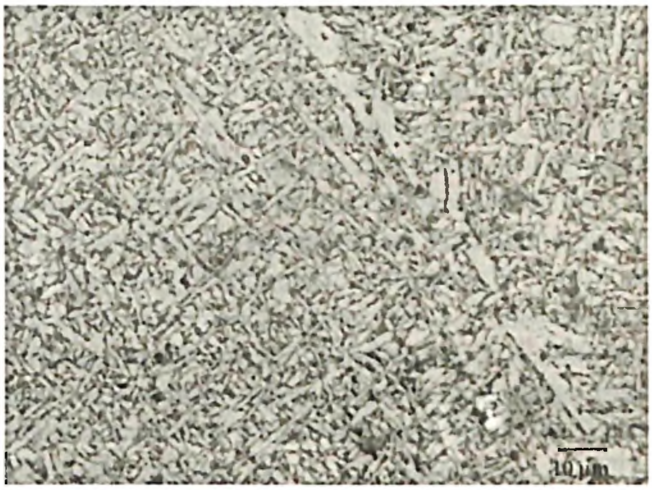


Fig 4. Photo of Microstructure of Line Pipe Weld Joint with 14.53 consisting of acicular ferrite and some grain boundary ferrite

To increase the strength beyond that of acicular ferrite, obvious route is to allow development of lower transformation products, bainite and martensite. Users of consumables already in the market report two potential problems as the strength rises. First the properties, in particular the yield and the tensile strengths, become unduly sensitive to the thermal history of the weld. Secondly high strength weldmetals have an increased sensitivity to hydrogen induced cold cracking. Consumable developers face a dilemma – the very inclusion which allow the desirable acicular structures to be developed prevent their optimum. The way to improve the tolerance of weld metals to heat input variations, while at the same time also increasing the resistance to hydrogen cracking, is to aim for ultra low carbon bainitic microstructure or aim for the same property by producing a martensitic microstructure. Claims made for the advantage of a particular structure is not always substantiated, and mixed ferrite-bainite-martensite structures often perform as well as single types, which in any case is difficult to produce in a practical weld. Very low carbon contents, for example below 0.05%, do not necessarily offer advantages in terms either of toughness or of resistance to hydrogen cracking, if comparison are made at constant strength. The so called MA phase, a mixture of martensite and retained austenite, may actually be beneficial to hydrogen cracking resistance. It is now clear that increasing strength in itself do not increase the risk of HICC, even hardness, but presence of primary or grain boundary ferrite in such microstructure along with hydrogen can prove to be detrimental.

In practice, it appears that for yield strength below 690 Mpa, Oxygen content high enough for good weldability produce sufficient benefits. For eg., a new flux cored wire OK Tubrod 15.09 gives yield strength of more than 700 Mpa, with charpy value of > 47 J at −20°C. However for welds with higher toughness requirements, the low Oxygen route is essential: thus the basic tubular wire, OK Tubrod 15.27, used for penstock pipe fabrication, typically give charpy values in excess of 80 J at −50°C (Fig 4). For still higher UTS, all consumables are of low Oxygen type.

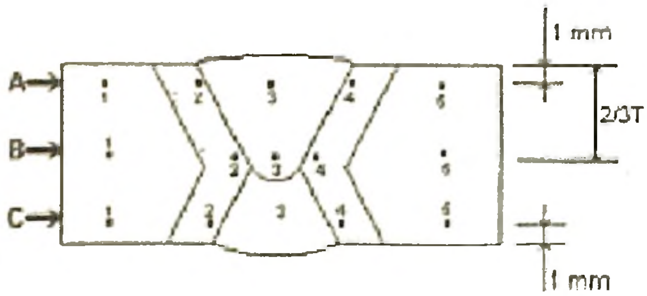


Fig 5. Joint design of a penstock pipe welded using cored wire

4.2 Small Diameter Cored Wires

The diameter of choice upto the 70's was the 2.4mm. As technology improved, end users were able to achieve comparable results and obtain all position capabilities from smaller and smaller diameter wires. Over 80% of ESAB's production is for diameter 1.6mm and less. The advantage of small diameter cored wire goes beyond welder appeal and deposition rates as high as 5.8 Kg/hr for 1.2mm wire and 9.1 Kg/hr for 1.6 mm wire. Emphasis on total cost to weld a structure including welding preparation and post weld cleaning of spatter is increasing. Government regulations also require that fabricators consider the well-being of their welders and cleanliness of the weld shop environment. ESAB's Ultra series of cored wires provide fabricators with a small diameter cored wire that has very low spatter reducing post weld clean up as well as low fume emissions. For those applications where critical weldments are required, Dualshield Ultra series provide not only low fume and spatter, but also exhibits extremely good mechanical properties including low temperature impact toughness. Cored wires for creep resistant as well as stainless steels also are now readily available in smaller diameters, staring from 0.9mm.

4.3 Metal Cored Wires

There is currently a movement underway by fabricators to change from solid wires and rutile slag E71T-1 cored wires to a metal cored wires. The obvious advantage of high deposition rates similar to flux cored wires coupled with high efficiencies similar to solid wires make metal cored wires very attractive. They also offer less failures in some applications due to better penetration and side wall fusion over solid MIG wires. Another advantage seen in case of metal cored wires is that less heat input is required to per weld metal deposit – operators can use lower current levels for thin gauge materials and eliminate distortion. Less tack welds are also required, saving labour. ESAB's line of Coreweld metal cored wires are designed to meet the requirements of an AWS A 5.18 electrode while providing an excellent spray transfer with reduced fume generation and spatter. Post weld cleanup of spatter is all but eliminated resulting again in labour savings. In addition to the line of mild steel metal cored wires, many end users prefer metal cored over solid wires when a specific alloy composition is required. Because of the ability to produce small batches of fabricated wires, capability to custom make any types of low alloy metal cored wires can be manufactured (Fig 6a and 6b).

Fig 6a. Bead shape of Metal Cored Wire : Coreweld 111 RB

Fig 6b. Micro and Penetration of the above Metal Cored wire

Demand for wires packed in **Marathon Pac**® also are growing due to actively pursued automation needs as people realize the massive advantage of feeding from a straight wire. Not only is down time for changeover dramatically reduce from the bulk package, but Marathon Pac® wire feeds extremely easily and has less effect on the wear of the feeder, liner, and contact tips.

Marathon Pac® solid MIG and cored wires are now readily available indigenously in packages ranging from 100 – 250 Kgs. Welding fabricators with Automated / Mechanized and even stand alone machines who have converted to wires packed in this novel packaging from smaller 12.5/ 15 Kg spools have experienced significant improvement in their productivity.

5.1 Shipyards rely on cored wire welding

Typical example of extensive usage of low diameter flux cored wires can be found in almost all industries today. For eg., in Asian Shipyards, flux cored wire usage account for the vast majority of welding, more than all other processes put together, as high as 70%. Metal Cored or high efficiency wires are growing in importance, especially for automated flat position fillets (Fig 7). Post weld clean-up cost along with ease of slag removal is a key issue. CO_2 is essentially used as the shielding gas due to reasons of cost, availability and cool operation of the welding torch. Most butt welding operations are carried out using one sided technique using ceramic backing tapes to avoid back gouging and re-weld. Cored wires have been developed to provide good bead shapes, mechanical properties and crack free welding in this specialized application. As most shipbuilding steels are pre-painted with Zinc rich primers, the wires also have capability to produce defect free fillet welding over these primers. As the large size of many ships make preheating impractical or impossible, wires used are capable of depositing reliable welds without preheating. In many cases welding operators are paid in relation to their measured output – the operators are therefore expectedly critical of any wire feeding or packaging problems which may reduce their output.

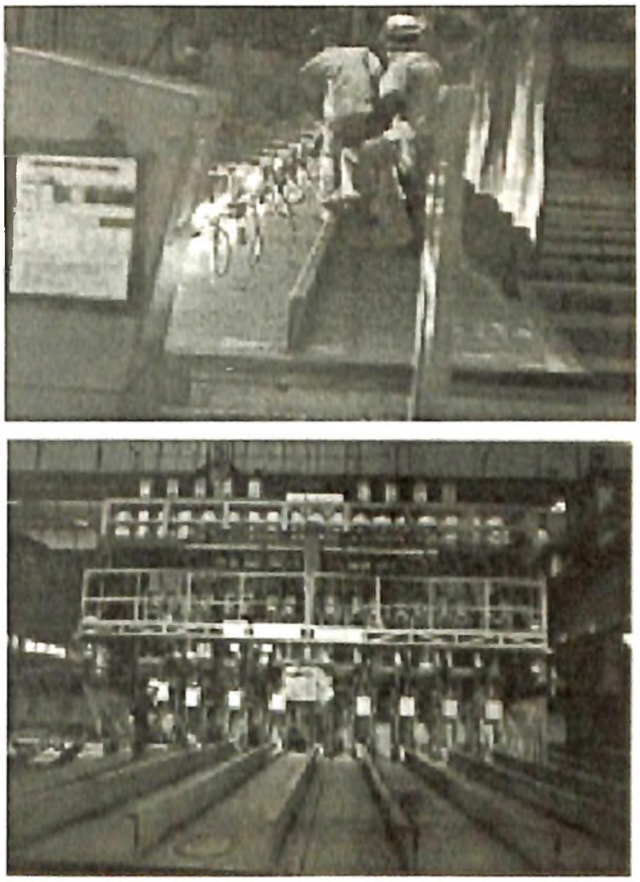


Fig 7. Mechanised cored wire welding system at a shipyard (left –gantry type single torch, right – TAMA type twin tandem with 24 torches)

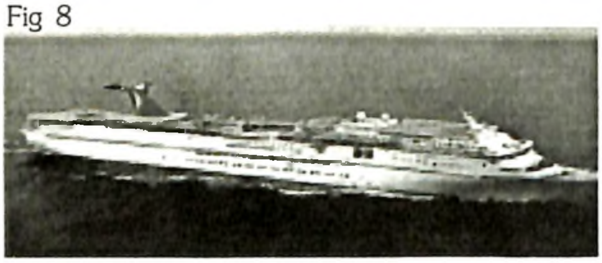
All these issues are carefully considered in selection of a cored wire for different types of joints and applications in a ship (refer table 1 and fig. 9) respectively.

Table 1 : Application Status of FCAW in an Asian Shipyard

AWS Code	Brand Name	Application	Usage Rate
5.18 E 70C-6C/M	CW Ultra	Tack Welding	5%
5.20 E 70T-1 CW	111 RB	Fillet Welding for anti-porosity purpose	15%
5.20 E 70T-1	DS R 70	Fillet welding for large length (>8mm)	15%
5.20 E 71T-1	DS 7100	All Position (2Y)	45%
5.29 E81T1-K2	DS II 81 K2	All position for low temperature steel service (4Y, 5Y) 20%	

Welding parameters for high speed welding of fillets using CW 111 RB include 35-48 cm/min for single torch and 85-150 cm/min speeds for twin torch, with stick out of 25 mm, 50°angle and currents upto 430 A/36 V. For high leg length fillets of 8 mm minimum. DS R 70 is used with 300-350 A, 35-37 V, 20-50 cm/min. Complex vessels such as gas carriers, offshore rigs and FSPO's LNG carriers and even passenger ferries are nowadays fabricated using cored wires extensively. Fig 8 below shows a completed ship which had extensively used cored wires.

Fig 8



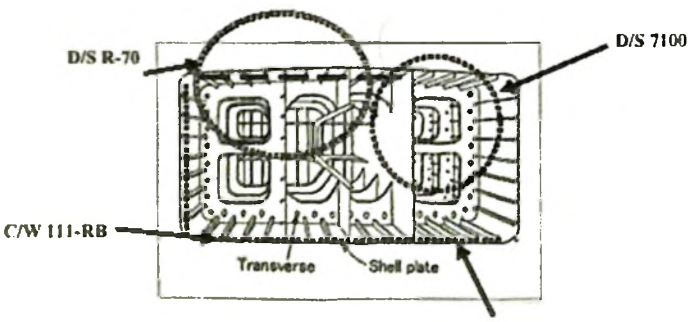


Fig 9. Welding of various parts of a ship with specially developed cored wires

5.2 Cored Wires Speed up Production of Railway Rolling Stocks

One of the significant applications of cored wires can be found in production of railway rolling stocks and bogie frames made of St 37 and St 52 types of steels. Another metal cored wire OK Tubrod 14.12 used by robot for welding bogie pivot assembly (Fig. 9) – one can see smooth welding appearance and lack of spatter. Similarly 15 mm thick collars are circumferentially welded to the central tube at 280-300A which will produce a deposition rate of 6.5 – 7.5 kg/hr deposit depending on electrical extension. The joint is completed by robots using two passes with oscillation and without stopping for inter run cleaning. This is made possible by the very low volume slag, which when welding over the first pass, floats up through to the second pass. Unlike the slag produced in flux cored wire, which is usually in larger volumes, that produced by metal cored wire is extremely thin, appears as small islands and being brittle will self release when the weldmetal cools. This quality and minimal spatter has contributed considerably to savings in cleaning time. Other applications include fabrication of internal superstructure of a passenger car from high tensile Q & T steels like T1 or R-70 (Fig 10). The main chassis steel varies in thickness from 6 –25 mm; the R-70 steel is air hardenable (CE = 0.55%) necessitating preheating between 70 – 140°C. The T1 steel is welded using OK Tubrod 14.03 and R70 with OK Tubrod 14.12 (typical UTS of 660 Mpa meeting AWS E9XT-X). A number of fillet joints for the chassis was completed with 14.03 using high speed multi-pass technique, which is preferred to heavy deposits and fewer passes to minimize heat input. For the coupling houses, 14.06 was used.

Fig 9. Railway bogie pivot assembly using OK 14.12 wire

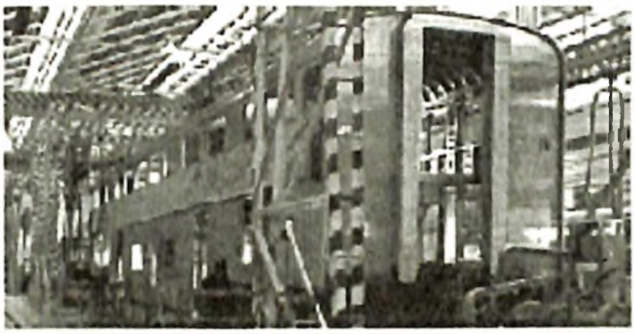


Fig 10. Double Deck Passenger Car Welded using 14.06/14.12

5.3 Cored Wires welds a Suspension Bridge

An approach span of a suspension bridge (7 X 193 m) made of thermo mechanically treated Fe 420 KTM steel of 10-30 mm thick (YS 420 Mpa min, 40 J at –40°C) has been welded – all root passes and for filling the side and the bottom. Fig 11 below gives an overview of the joint types, positions and welding processes. All joints apart from the downhand filling of the deck joint (SAW) were done using Filarc PZ 6138 metal cored wire. This is a CTOD tested, all position rutile cored wire with Ti-B alloying and 1% Ni microalloying, with impact toughness down to –40°C

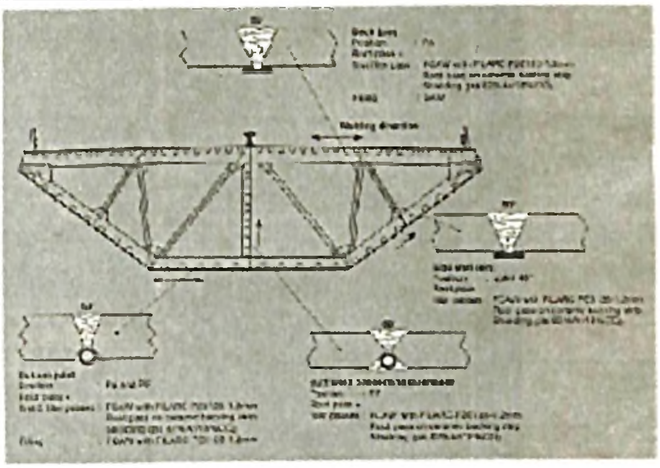


Fig 11. Cross section of an approach span of a suspension bridge shown with the joint design and welding process used

A new generation, all position basic flux cored wire PZ 6125 is used for the root run to avoid possibility of hot cracks associated with rutile wires when welded with high currents and in down hand positions.

5.4 Automotive exhaust system welding with cored wire

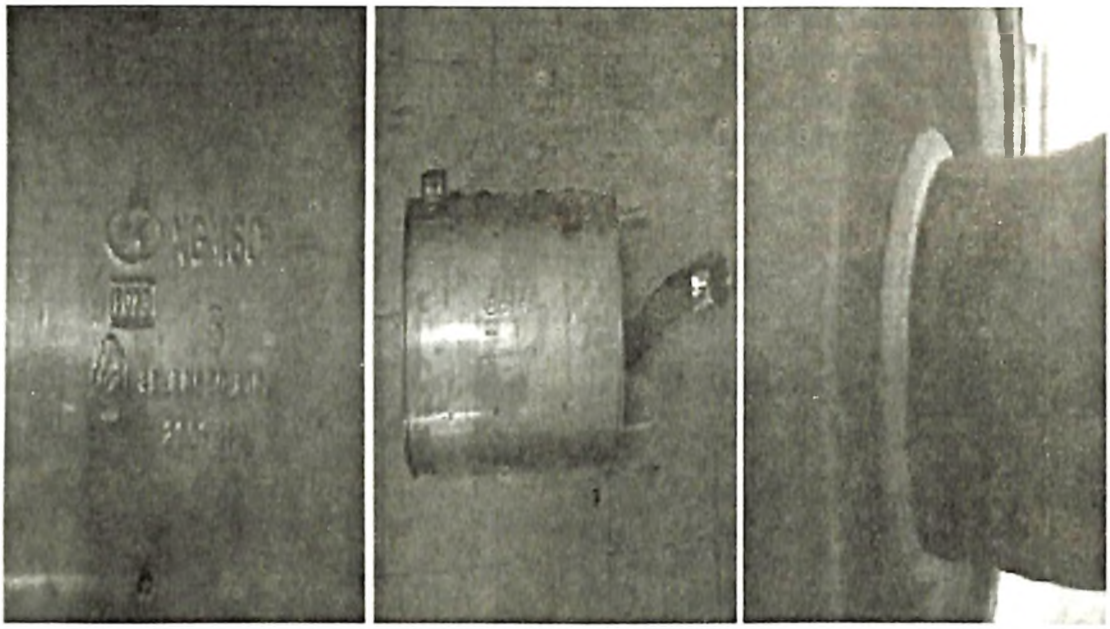
Automotive exhaust of 409M pipe is welded to carbon steel flange using Arcalloy 409Ti type wire

Fig 12. Bead appearance of Horizontal fillet welding

Welding condition : 24V x 220A, 98% Ar/ 2% O2

Sample	Bead appearance	Remarks
409Ti		- Clean bead - small spatter - equal leg length
436		- Small spatter - Little slag - Nearly equal bead

This wire deposits an excellent fillet joint with almost equal length and nearly nil spatters. Optimum welding parameters are 200 – 260 A, 22 – 28 V for 1.2mm dia wire with 15-25 mm stick-out.



5.5 High Speed Cored Wires for Excavator Booms

Switching to cored wire welding from MIG proved to be a boon for the critical welding of the boom of an excavator. Typically for manual welding of a 6 mm throat thickness, wire feed speed of 12 m/min at 400 A in CO_2 shielding gas is normally used. Keeping the same current level in case of a high speed metal cored wire of the type PZ 6111 HS, 1.6mm dia, the speed increased to 14m/min. The fillets are flat to slightly concave in nature with a very smooth tie in and no tendency towards undercut. With adequate penetration and very little presence of easily detachable slag, the ultimate productivity increased between 8-12% (Fig 13, 14)

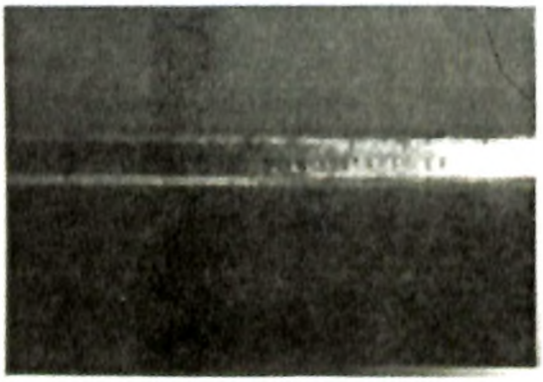


Fig 13. Filler weld in an excavator boom, using PZ 6111HS, 1.6mm

Fig 14. An excavator boom

5.6 Cored wires for SAW

One of the latest development in field of cored wire welding is that of SA Welding with and with it the transfer of productivity benefits. Cored wires for SA Welding, with minor variations in formulations to take account of alloying contributions, are essentially similar to those available for the gas shielded process and are available in sizes 2.4-4.0mm. Compared to solid and basic cored wires, deposition rate with SAW cored wires at the same welding current are 20 – 30% higher(Fig 15). Cored wires for SAW may be used on standard equipment, with updated gearing speed of the wire feed motor to take care of increase due to cored wires.

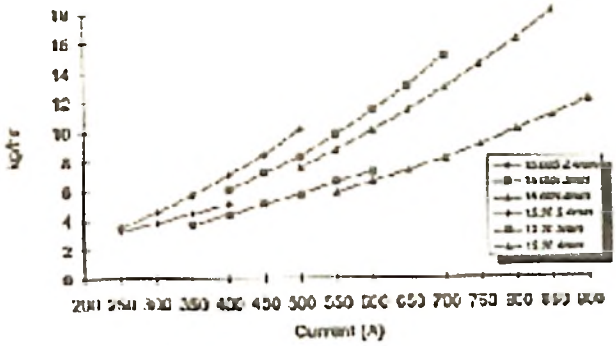


Fig 15. Comparison of SAW deposition rates with solid and basic wire

One example of a successful application of cored wires for SA Welding of 1 X 1 metre structural plates of thickness 20 – 50 mm using OK Tubrod 15.00S and OK Flux 10.71L. When using solid wire of 4mm dia at 720A/36 V typical welding speed was at 0.25-0.30 m/min. Changing to cored wire led to increase in the welding speed to 0.35-0.40 m/min, a 30% improvement (Fig 16). Other successful applications include one sided SAW in shipyards, hard surfacing, etc.

5.6 Others

Small dia cored wires (0.9mm and above which can be used with 100% CO_2 as the shielding gas are also now available which offer welding fabricators improved productivity, better quality and reduced costs as well as broad range of alloy modifications. Wires are available for welding of duplex as well as Superduplex SS with successful application records are available. Rutile flux cored wires for all position welding of creep-resistant steels also have been developed (Table 2). Table 3 provides typical welding parameters for vertical – up welding of Duplex SS Chemical Tankers.

Fig 16 : SAW installation for box beam welding

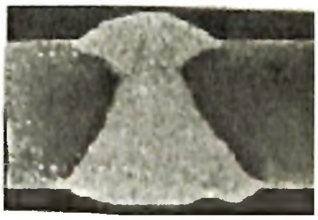
Wire	C	Mn	Si	Cr	Ni	Mo	N	PRE*
OK Tubrod 14.37/CO_2	0.03	0.90	0.65	22.5	9	3.1	0.15	35
OK Tubrod 14.27/ Ar + CO_2	0.03	0.90	0.90	22.5	9	3.1	0.15	35
OK Tubrod 14.28 /Ar + CO_2	0.03	0.80	0.90	25	9	3.7	0.22	41

*PRE = %Cr + 3.3%Mo + 16%N

Table 2: Typical weld metal chemistry of cored wires for duplex/superduplex SS

Table 3. V-up welding of 12mm plate welding using 14.27 for chemical tankers

Position	Joint Type	t_{plate}, mm	I, DC+, A	U,V	HI, KJ/mm	FN	Mech Prop
PF (3G)	V6°	12	150-170	24	1.0-1.2	47	CVN at -30°C
							Centre 53 J
							Fusion Line 85 J
							Fusion Line + 2mm 109J
							UTS : 790 Mpa



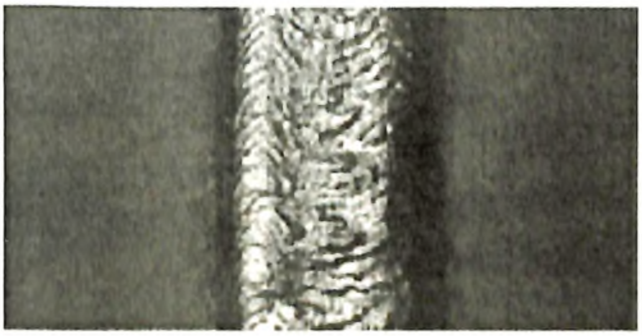


Fig 18. Joint Geometry & Penetration (Top), bead shape(middle) and welding setup (bottom) of V-up welding of 12m :hick Chemical Tanker of Duplex SS with 14.27

6.0 Conclusion

A good knowledge of the FCAW process and awareness of the fields of excellence of individual cored wires will help welding engineers to bring about tremendous advantage in terms of quality of welding fabrication as well as productivity improvement. The quality and productivity of cored wire vary from one manufacturer to another depending on the manufacturing process and associated flux formulations. Flux formulations in cored wires can be utilized to achieve optimal combination of mechanical property, weldability and productivity for a variety of applications. Lot of new types of cored wires have been successfully used for a variety of applications, resulting in tremendous increase in productivity and decrease in cost. Consumable price is generally more than repaid by much better welding economy.

7.0 Acknowledgement

The author is thankful to the management of ESAB India Ltd for the permission to publish this paper. ESAB Group has not only been a steady supplier of cored wire since the late 1950's, but is well known for being a high quality producer as well as a leader in innovation and cored wire technology.

8.0 References

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