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Weld Overlay Restoration of Forged DI Pipe Moulds

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Abstract

In this article, the procedure for restoration of forged ductile iron (DI) pipes through the application of weld overlay is discussed. After several trial tests, an optimum composition of the metal cored wire has been found out for overlaying a range of mould materials. Metal-cored wires of 2.4 mm and 3.2 mm diameter have been found to be the suitable sizes for overlaying of small, and large moulds of more than 800 mm respectively. Quite large moulds of 1500 mm and above have been welded successfully using 4.0 mm metal cored wires typically at 650-680A and at a weld deposition rate of over 7.5 kg per hour with heat input up to 2.60 kJ/mm with a control of preheating and reheating temperatures.

I would like to thank IIW India for inviting me to deliver the prestigious Sir L. P. Mishra Memorial Lecture. Sir L. P. Mishra was a Chief Engineer with The Indian Railways, and after his retirement he joined Hindustan Motors Ltd as a Director, a position he held till his death in 1964. He was an eminent engineer with special interest in welding and he was the first Chairman of the Indian Branch of the Institute of Welding, London. He was one of the chief architects in forming the Indian Institute of Welding. The Council of the Institute of Welding, London encouraged members to form an Indian Institute. Sir L. P. Mishra facilitated the process by agreeing to transfer the assets of their Indian Branch to the new Institute. The Indian Institute of Welding was formed as a Limited company following the application made to the Government of India on 22nd April 1966. In 1974, IIW-India instituted the Sir L. P. Mishra Memorial Award Lecture in his honour. We would like to remember him today and pray for his soul.

Introduction

Welding encompasses a vast arena of engineering science and throws up many challenges from the industry, not only in terms of achieving soundness of welded joints but also to restore worn components to their original properties and dimensions. I would like to share one of these applications with you and discuss the considerations regarding perfecting the procedure in order to obtain the best results in terms of performance life of the restored component.

Ductile iron pipes, as the name suggests, are more ductile than ordinary grey-cast iron pipes, and bend under pressure instead of breaking. These pipes are used for potable water transmission and distribution. External and internal coatings such as polyurethane and cement mortar are often applied to these pipes to inhibit corrosion. They have a large life span. These pipes are manufactured using a centrifugal casting process.

Manufacturing Process

The process involves using molten recycled and shredded steel in a melting furnace and then forming iron using deoxidizers and Magnesium. The molten iron, with harmful impurities removed, is then poured into a mould of a defined size in a centrifugal casting machine and extracted out using a consumable core.

Moulds

The moulds used are low alloy steel forgings, typically 15CrMo, 21CrMo10, 30CrMo, 35CrMo or similar, as the most relevant property of the mould material is to withstand deformation at elevated temperatures. During casting, the molten metal hits

Fig. 1 : Centrifugal casting and extraction of ductile iron pipes

the inner surface of the mould at 1400 Deg C and within a few seconds cools down to 800 deg C by way of external cooling of the mould in the casting machine.

Typically, a 6 meter long pipe is extracted out in about 15 seconds and the temperature of the pipe at the point of extraction is around 750 deg C. This means that the mould is subjected to a thermal cycle of 1400 - 800 deg C in 15 seconds for each pipe produced. Repeated thermal cycles result in a 'thermal fatigue' in the mould. This has a direct bearing on the mould design, i.e. the material of manufacture, the wall thickness and length of the mould.

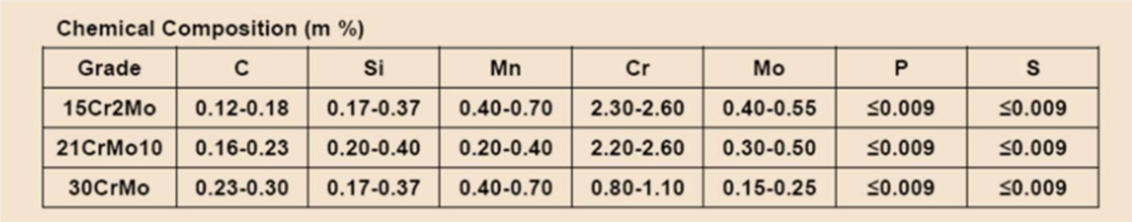
The pipe diameters vary from 100 mm to 1500 mm typically, although there are larger mills that produce pipes up to 2200 mm. The mould wall thickness therefore increases with the diameter and wall thickness of the pipe produced. The selection of mould material may vary with the size of the pipes produced. The deformation resistance required at elevated temperatures increases for larger pipe sizes.

The moulds are manufactured using cylindrical forging process. There are residual stresses left in the mould during their manufacture which may add to the elevated temperature stresses during pipe production.

Mould Wear

During the production of the pipes, a typical cycle of the thermal stresses acting on the mould surface are graphically depicted below.

The mould mouth from where the pipe is released, undergoes abrasive wear in addition to the cyclic thermal stresses. Even though the shape of the mouth (Refer to the drawing below) is designed to release the pipe as smoothly as possible, the metal-to-metal abrasion cannot be completely avoided.



Chemical Composition (m %)

Grade	C	Si	Mn	Cr	Mo	P	S
15Cr2Mo	0.12-0.18	0.17-0.37	0.40-0.70	2.30-2.60	0.40-0.55	≤0.009	≤0.009
21CrMo10	0.16-0.23	0.20-0.40	0.20-0.40	2.20-2.60	0.30-0.50	≤0.009	≤0.009
30CrMo	0.23-0.30	0.17-0.37	0.40-0.70	0.80-1.10	0.15-0.25	≤0.009	≤0.009

Fig. 2 : Typical composition of the forged mould steel grades

Fig. 3 : Typical mould employed in DIP manufacturing

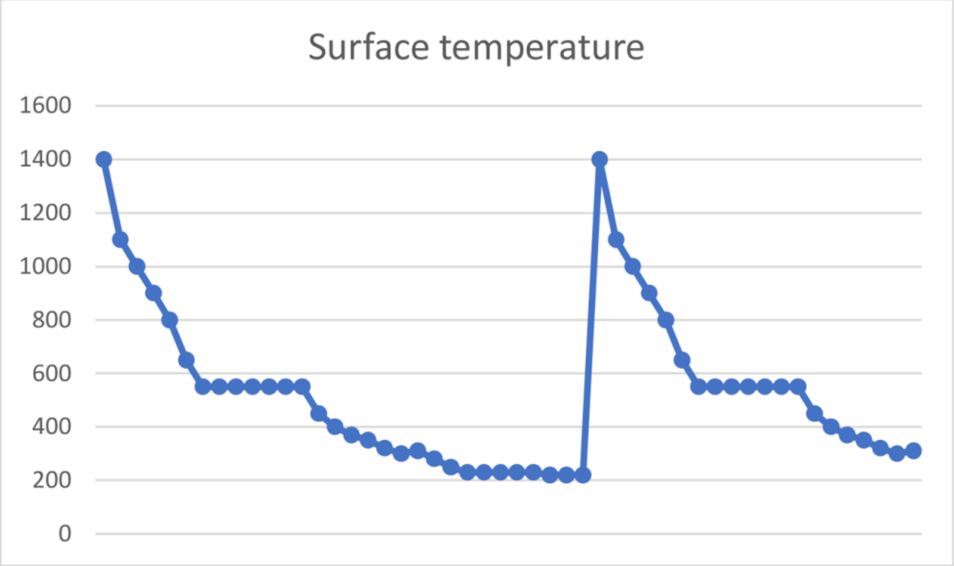


Fig. 4 : Thermal stress cycle on the moulds (Temp vs time)

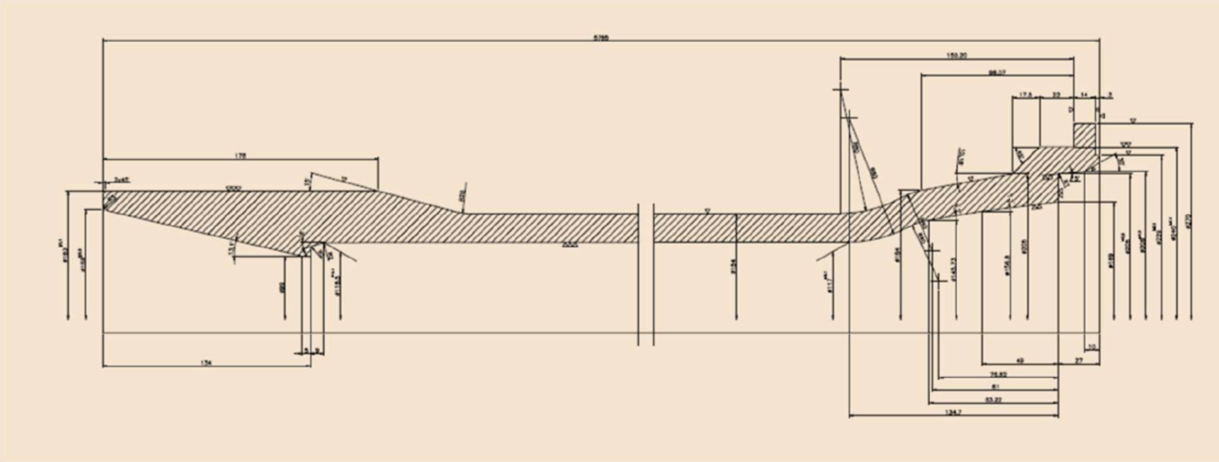


Fig. 5 : Intricate shape of the mouth and tail of a typical small mould

The mould mouth and tail, therefore, undergo radial wear and during its production life the mould needs to be pulled out of the centrifugal caster, for restoring its mouth and tail dimensions by weld overlaying, followed by machining and peening for improving the gripping of the pipes.

Welding of Moulds

The most optimum overlaying process is submerged arc welding primarily for high metal-deposition rates and increased productivity. Welding is automated by rotating the mould at a constant speed and using a long stationary welding gun that can traverse inside the mould mouth stepping a fixed distance after every revolution.

The moulds are welded under submerged arc using metal-cored wires of tailored composition to suit most of the grades and using a high basic flux to ensure impurity-free welding.

The mould sizes vary with the sizes of the pipes produced and require a rotator and a continuous welding set up for sub arc welding. The equipment set-up is shown in the figures below.

Fig. 6 : Sub arc welding of moulds and continuous heating of large moulds

Fig. 7 : Sub arc welding set-up with a long gun

Delayed or cold cracking in large moulds

Since the moulds material is low alloy steel of high thickness, overlaying on a relatively smaller mass of the mould can cause thermal ingredients resulting into high residual stresses. Moreover, microstructural changes in the Heat affected zone (HAZ) may result in formation of martensite and subsequent cracking in the HAZ.

This cracking is sometimes seen in large diameter moulds, and the cracks appear 4 or 5 days after welding. These are cold cracks that initiate in the HAZ and propagate to the surface rapidly thereafter.

Metallurgical Considerations

The metallurgical factors under consideration are the steel grade of the mould, carbon content, net Alloy content, wall thickness, the Ms (martensite start temperature during cooling) of the mould, the Heat input of the weld, which essentially varies with the diameter of the wire used and the currents employed.

The combined carbon and alloy content of the mould steels is sufficiently high to promote formation of martensite at relatively slow cooling rates, and without preheat martensite in the HAZ cannot be avoided.

Fig. 8 : Delayed cracking in large diameter moulds

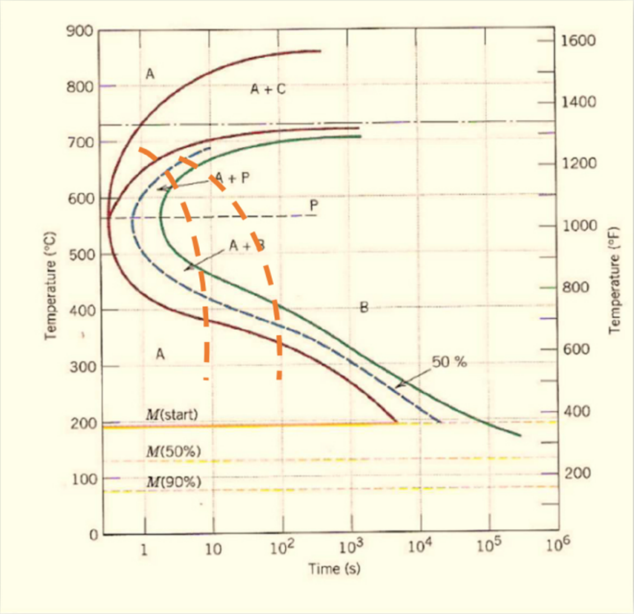


Fig. 9 : CCT diagram and superimposed cooling rates of a 0.2%C steel

Moreover, high hardenability increases the sensitivity of thee steels to hydrogen, and the possibility of hydrogen cracking is significantly higher than that of other carbon steels.

Therefore, during welding the martensite formation needs to be suppressed by providing adequate preheat above the Ms temperature of the mould material before and after welding and then continue to heat to bring up the temperature of the mouth of the mould uniformly to 250 deg C, i.e. well above the Ms temperature of the mould steel, before slow cooling.

Ms temperature of most of these forging grade steels is around 180 deg C. and increases gradually with carbon content. (Refer to **Fig. 9** showing CCT of a 0.2% C containing steel).

The deposition rate is also relevant from a production standpoint. The most optimum size of the wire is the one that provides maximum acceptable deposition rate. Since the welding process is automatic, a reference to the diagram below shows that the 2.4 mm and 3.2 mm wires can be effectively employed at 30-34 V and 450 – 600 A range to provide optimum deposition rates without running the risk of increasing the size of the HAZ and increasing the vulnerability to crack initiation in the HAZ.

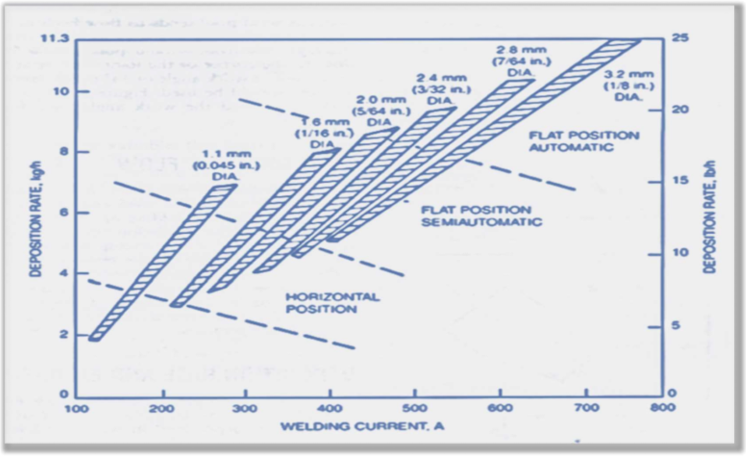


Fig. 10 : Deposition rate of tubular cored wires vs. welding current

Heat input

Welding heat input expressed in kiloJoule per mm of weld = 0.06 V*I/S where:

V = Arc Voltage,

I = Welding current, and

S =Surface travel speed = $2\pi r$ * R mm/min,

where r is the radius of the mould and

R = speed of rotation expressed in RPM (revolutions per minute)

For a 3.2 mm wire welded at 32V, 480A for overlaying on 800mm dia mould rotating at 0.2 rev per min.:

Typical Heat input = 0.06*32*480 / 2*3.142*400*0.2
= 1.83 kiloJoule/mm

Typical deposition rate = 7 kg per hour

Conclusions

After many trials and studies, it was concluded that an optimum composition of the metal cored wires can be employed for overlaying a range of mould materials without matching or overmatching the base alloy composition, and metal-cored wires of 2.4 mm and 3.2 mm dia are the most optimum sizes for overlaying of smaller (<800 mm) and larger (>800mm) moulds respectively. Large moulds of 1500 mm and above, have been welded successfully using 4.0mm metal-cored wires typically at 650-680A and at a weld deposition rate of over 7.5 kg per hour, with heat input best limited to 2.60 kJ/mm and with control of preheating and reheating temperatures.