WELDING OPTIONS IN STEEL CONSTRUCTION

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1. Introduction

In India the use of structural steel has been growing and it has become an important input material for construction. Any development of new steel application also depends on matching development of the welding sector. Thus cost effective welding is important in steel intensive construction as reliability; durability and safety of the structure. These are ensured through the strength of the fabricated joints .The standard structural steel is having tensile strength of 410-430 MPa (min), and good weldability. The reasons for preferring structural steels are shown in table 1.[1]

Table 1: Preferred Properties of structural steel

Features	Reason
Light Weight	Structural steel having high specific strength
Durability	Reduces overall costs through longer service life
Ductility	Ability to deform after yielding
Shear Strength	To prevent instantaneous collapse
Weldability	Base material besides weld consumables and process.
Young's Modulus	Resistance to being deformed.

2. Structural steel grades used for Construction

2.1 Plain carbon structural steel

Steel commonly known as mild steel made as per IS: 2062 Gr. A, B and C is widely used in Indian general construction sector. These steel plates have very good weldability but due to low strength relatively thick sections are required for a load bearing applications.

2.2 High Strength Low Alloy

These steels have been covered under IS 8500 specification. Modern structures need higher strength steel in order to reduce weights of structures so as to achieve economy. Hence thinner sections of these grades are used in applications in compare to mild steel. Again by ferrite grain refinement with micro-alloying element like Ti, Nb and V (<0.2% wt) the strength of steel is further enhanced to tensile strength of 400–720 MPa with good weldability and impact toughness at subzero temperatures. [2]

2.3 Weather Resistance Steel

This steel is preferred as construction material in coastal areas and confirms to IS 11587. These steels may be fabricated in the same manner as ordinary structural steels of the same strength. For all welding procedures, appropriate minimum pre-heat temperatures should be used. Proper electrode should be selected in order to remove the possibility of hydrogen induced cracking.

2.4 Fire Resistant Steel

Normally used in important structural members (column and Beams) of buildings can decrease or eliminate the need for fire insulation coating. With the addition of Cr and Mo yield strength is retained at $600\ ^0$ C (Yield strength drops to two third of Room temp value when heated at $300\ ^0$ C.)[3]

3. Different forms of Steel

3.1 Reinforcing steel

As per IS 1786 all the bars are weldable at site for all types of joints provided Carbon Equivalent is known (less than 0.51 is easily weldable). Satisfactory strength is achieved by judicial selection of weld design and welding practice.

3.2 Closed Structures

Due to their high torsional rigidity and compressive strength, closed structures behave more efficiently (40% metal saving) than conventional structures. The smooth, uniform profile of these sections facilitates easy fabrication at site. These hollow sections are weldable with standard electrodes without any preheating available. These are made as per IS 4923.

3.3 Galvanized steel

It is a generally used in conventional structures and can be welded like uncoated steel if the zinc coating is locally removed (at least 25 mm on each side of the joint). Zinc remaining in the weld area as contamination of the weld pool will lead defects like weld embitterment, Porous welds, Spatter.[4]

3.4 Pre-Painted steel

Pre-painted sheets are being used in construction very often for elegant and aesthetic look. All surfaces to be incorporated into the weld itself should be thoroughly cleaned of all coatings or contaminations, and dry immediately prior to welding. [4]

3.5 Stainless steel

Often combination of stainless steel and various structural grades need to be welded. This becomes natural choice in the high corrosivity area or imparting special architectural feature. Welding of this steel with general structural steel obviously leads to a mixture of two-weld pool. Hence welding should be carried out as per proven welding procedure specification.

4. Welding Technology

Welding is very essential in case of heavily loaded site connection, rigid connection and even in refurbishment job. The overall economy may be achieved thru the selection of right type of weld joint, edge preparation, selection of weld process and selection of filler materials. The most commonly used techniques are for welding of structural steelworks [5]

a) Shielded Manual Metal Arc Welding (SMAW)   b) Metal Inert Gas Welding (MIG)
c) Submerged Arc Welding (SAW)   d) Stud Welding

4.1 Stud Welding

 It is a process by which metal fasteners are welded rapidly to the surface of metal components and an electric arc is used to produce necessary heat for fusion weld. The process is actually a combination of heat and pressure. A typical stud welded composite beam with shear connector is shown in fig. 1. [6]
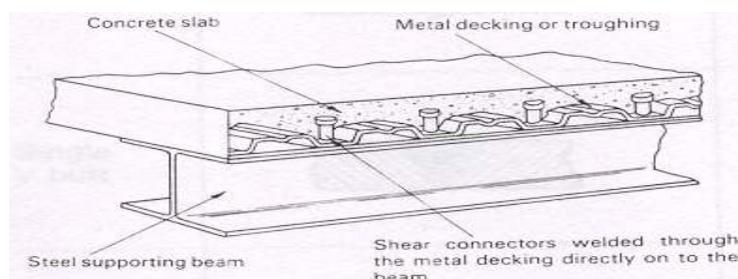

Fig 1: Cross Section of Composite Beam with Shear Connectors

5. Cost Effective steps

5.1 Welding Consumables

The consumables like electrodes normally conform to IS 814/IS 815. Welding technique is in accordance with IS 816 / 9595. High tensile steel electrodes should comply with the requirement of IS 1442.Consumables offer combination of high strength, adequate ductility and required toughness even at subzero temperatures. The weld metal systems are generally based on alloying combinations of C-Mn-Ni-Mo and perhaps Cr, in terms of microstructure a large difference exist between weld deposits of higher strength and weld deposits of lower strength. The addition of Mo around 0.5% raises the yield strength by 100 MPa with slight reduction in ductility. Table 2 below shows the strength of weld metals from covered electrodes.[7]

Table 2: Welding of steels in 450 MPa yield strength class

Yield Strength Mpa	Typical Strength (J at –40 ^{0} C)	
450	80	Strength of weld metals from covered electrodes
520	150	
540	120	
610	70	
640	125	

5.2 Shift from process

Manual metal arc welding process is being gradually replaced by flux cored arc welding and is being increasingly used for relatively higher strength structural steels. Apart from the main advantage of higher productivity in welding, the process offers welding with lower heat input, which favours suitable microstructure formation in weld and HAZ of high strength steels. Various alloy and micro alloy additions are easily possible through flux cored arc welding (FCAW).[7]

5.3 Avoid Risk of Cracking

If the carbon Equivalent (CE) of a steel exceeds 0.4, the welding situation changes due to the possibility of cracking in the heat affected zone (HAZ) .And due to increase in volume of martensite, cracks will usually develop—the phenomenon called under-bead cracking. Thus proper care will save welding rework/rejection. A typical HAZ is shown in fig 2[8]
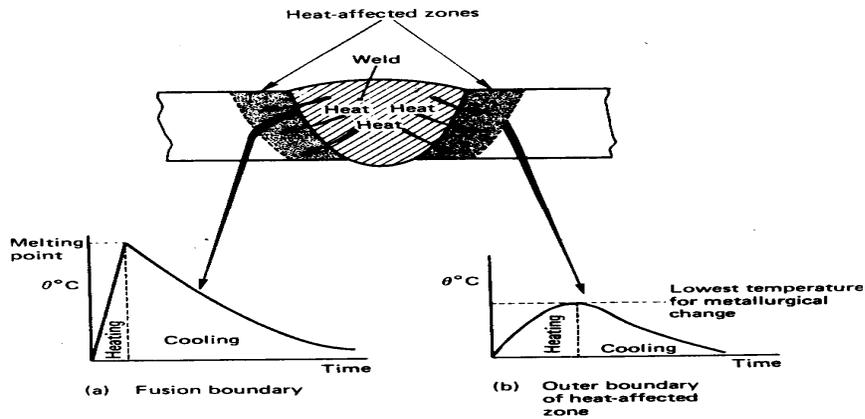

Fig 2: Heat Affected Zone Boundaries

The interdependence of factors like CE, cooling rate, heat input, joint type and thickness, hydrogen content and preheat are governing HAZ cracking. Fig 3, can help choosing an appropriate combination to avoid the risk of cracking.[8]
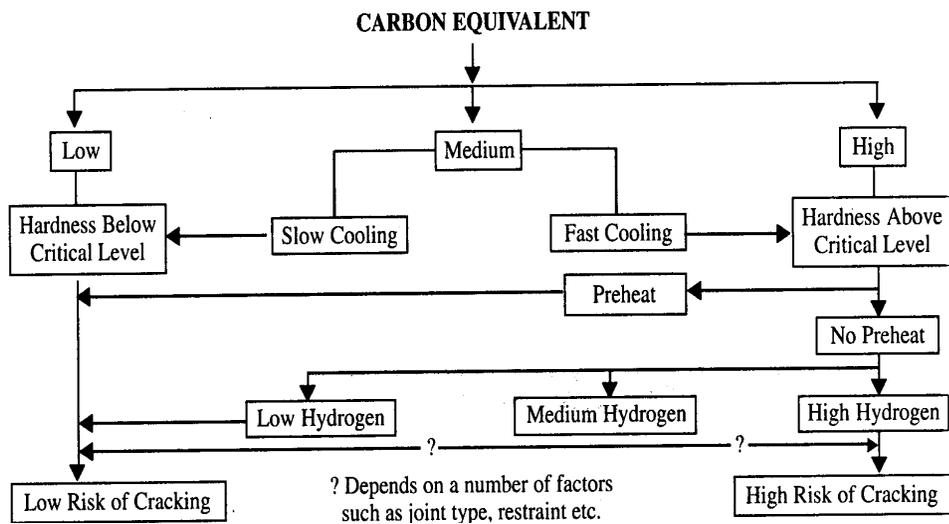
Fig 3: Principle Factors Affecting Cracking Tendency of HAZ

5.4 Pre heat and Interpass temperature

It is a function of steel type and thickness. In case mild steel there are two options available a) coated electrodes other than low hydrogen, b) low hydrogen electrode. Table 3 provides the guideline.[9]

Table 3: Minimum preheat temp and interpass temp as per AWS 1.1

Steel Type	Welding Process	Thickness of thk part ,mm	Min temp ^{0}C
Mild Steel	MMA with electrodes other than low hydrogen type	Upto 19 20-38 39-64 Over 64	None 66 107 150
Mild and medium tensile steel	MMA with low hydrogen electrode, Submerged arc, Gas metal arc, Cored wire	Upto 19 20-38 39-64 Over 64	None 10 66 107

5.5 Avoid Distortion in Steelworks

Stresses are induced by the unequal expansion and contraction of the weld metal, the heat affected zone and unaffected base metal during welding. Also depends on number of weld run, conditions of the parts to be welded, amount of weld metal deposited, extent to which parts are free to move. These distortions may be avoided by adopting proper welding procedure, planning welding sequence for correct angular distortion, Preheating parts prior to and during welding.
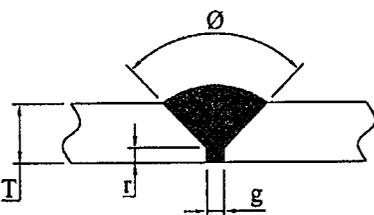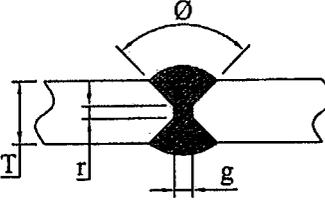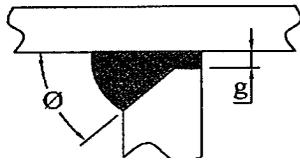
6. Weld Economics

Welding costs have been calculated by many methods taking into account the design, shop-floor procedures and repeatability of a product, length of weld, overheads etc. Usually the cost of weld metal is about three times the cost of steel. Very often, the economics of welded fabrication is judged by the cost of electrodes, arc times etc. The low hydrogen electrodes are apparently costlier than rutile electrodes. However, in terms of the efficiency and the integrity of the weld joints, low hydrogen electrodes are certainly cost competitive.

6.1 Calculation of weld metal volume

The following expressions shown in table 4 indicating theoretical cross sectional area of the weld metal deposit for different types of welded joints of different thickness with different root face and root gap without considering weld reinforcement and weld shrinkage into account.[5]

Table 4: Weld Metal Deposit Relationship

Joint	Sketch	Cross Sectional Area
Single V Butt Joint		$A = g.T + t^2 .\tan(\theta/2)$ Where g = root gap, T= plate thickness, t=(T-r), where r = root face and θ = including angle
Double V Butt Joint		$A = g.T + 2t^2 .\tan(\theta/2)$ Where g= root gap, T= plate thickness, t = (T-r) / 2, where r = root face and θ = including angle
Single Bevel Butt Joint		$A = g.T + 0.5\, t^2 .\tan\alpha$ Where g= root gap, T= plate thickness, t= (T-r), where r = root face and α = including angle

6.2 Cost Estimation for Single V Butt Weld [5]

Assumption: Without Backing Strip, Plate thickness 20 mm, Material as per IS: 2062 Grade-A, Included angle at joint as 60^0. Process GMAW (Gas Metal Arc welding), θ (Angle) = 60^0; T (Plate thickness) = 20mm; G (Root gap) = 2mm;

(Considering 95% deposition efficiency and specific gravity of steel 7.85 gms/cc) ,Arc Voltage = 30 volts (D.C Electrode Positive), Welding current = 350 amps; Wire feed speed = 600 m/hr. Atmospheric pressure = Normal, Ambient temp = 27 ^{0}C. Sp gravity of CO_2 gas = 1.79, Daily wages (for 8 hour) of welder as Rs. 150/- ,Overhead as 300% of labour cost. Ref fig 4
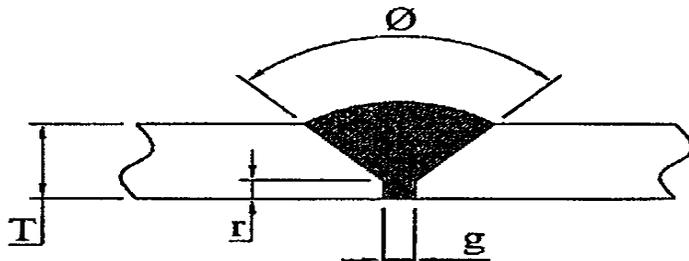

Fig 4: Typical Butt weld joint (Single V)

- Weld Cross sectional area = g. T + t^2 tan (θ / 2), = 0.2 X 2 + $(1.8)^2$ $\tan 30^0$ = 2.27 cc.
- r (Root thickness)=2mm; t = (T-r) = (20-2) = 18
- Volume of weld per metre   = (2.27 X 100) = 227 cc.
- Weight of weld metal   = (227 x 7.85 x1) / 0.95, = 1875 gm,   = 1.875 Kg
- Approx. weight of dia 1.2mm wire per metre ={(π X d^2) / 4 } X Sp.c gravity of steel
   = {3.14 $(1.2/1000)^2$ / 4 } X (1.0 X 7850) , = 0.009 Kg/m.
- Deposition Rate = (600 X 0.009) = 5.40 Kg/hr.
- Total arc on time required =(60 X 1.875) / 5.40 = 20 min.
- CO_2 gas flow rate = 20 Liter/min (approx.) as recommended by M/S Lincoln Electric, USA
   = 0.02 Cu M/min = 1.20 Cu M/hour = 2.15 Kg/hour

- Weight of CO_2 gas consumed in 20 minutes = {(20/60) X 2.15} = 0.72 Kg.
- Power consumed={(30 X 350) X (20/60) X 0.8}/ 1000, = 2.80 kWH.
- Cost of labour at 60% duty cycle = {150 / (8 X 60)} X {(20 / 0.6) } = Rs. 10.42

Table 5: Summary of Welding Cost by GMAW

Item	Quantity	Rate/Rs.	Amount/Rs.
1.2 mm wire	1.875 Kg	45.00	84.38
CO_2 gas	0.72 Kg	45.00	32.40
Power	2.80 Unit	4.00	11.20
Labour Cost			10.42
Overhead 300% of Labour Cost			31.26
Total cost of welding by GMAW			169.66 =$3.4

6.3 Cost Estimation for Single V Butt Weld [5]

Assume: Without Backing Strip, Process SMAW (Submerged Metal Arc Welding) ,Length of Electrode   = 450 mm, Length of Stub end =40 mm, (Weight of weld metal deposit with 90% efficiency, Effective length of electrode=410, Root Run with 3.15 mm dia electrode, Arc Voltage (V) = 34 volt, Welding current   = 150 amps, From IS: 9595, Arc Energy (AE)   = 2.5 KJ

- Weight of Weld Metal /metre length = {(227 X 7.85) / 1000 }X {(1/0.9)} = 1.98 kg.
- Weld deposit per electrode = {(π X d^2) / 4} X 41 cc
- Weld deposit per electrode of 3.15 mm dia = { (π X d^2) / 4 } X 41 X Sp gravity of steel (excluding stub end)   = {(3.14 X 0.315^2) / 4} X 41 X 7.85 = 25.08 Grams
- Welding speed={(VXA)}/{(1000XAE)}={(34X150)}/{(1000 X 2.5)}mm/sec=2.04 mm/ sec
- Arc travel time for root run (i.e. Arc on time)= (1000 / 2.04) =490 sec=8 min 10 Sec
- As per Table of IS: 9595 and corresponding to Arc Energy of 2.5 KJ / mm
- The Run Length of 3.2 mm electrode *(Containing little or no iron powder)* =85 mm

From First run

Assume: One similar weld run is to be applied on back seam after back gouging

- No. of electrodes consumed in root run = (1000 / 85) = 12
- Weld deposit in root run=25.08 x 12 = 310.96 gms.
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From second and third run

- Assume: 4 mm dia electrode, Arc Voltage (V)   = 34 Volt, Welding Current = 180 Amps, Arc Energy (AE) = 2.5 KJ / mm ,As per IS: 9595, Run length for 4.0 mm diameter electrode = 130 mm

- Weld deposit per electrode = {(3.14 X 0.4^2) / 4} X (41 X 7.85) = 40.44 gm
- Welding speed { (34 X 180)} / {(1000 X 2.5)}= 2.45 mm /sec.
- For each of second and third run, No. of electrode consumed = (1000 / 130) = 8
- Weld deposit = (40.44 x 8) = 323.52 gms
- Arc on time = (1000 / 2.45) = 408 sec= 6 min 48 sec

From fourth run

Assume: 5 mm diameter electrodes used, Arc Voltage =34 Volts, Welding current = 225 Amps, Limiting Arc Energy = 2.5 KJ / mm

- Weld deposit per electrode = {(3.14 X 0.5^2) / 4} X {41 X 7.85}= 63.19 gm
- Welding speed = {(34 X 225)} / (1000 X 2.5)} mm/sec = 3.06 mm/sec
- For each run Arc on time   = (1000/3.06) = 327 sec= 5 min 27 sec

- Total deposit with root and back run by 3.15 diameter electrode and second and
- third run by 4 mm dia electrode = (300.96X2)+(323.52X2) = 1248.96 gm
- Weld metal is to be deposited with 5 mm diameter electrode= (1980 – 1248.96)= 731.04 gm
- This weld metal deposit 731.04 gm is to be filled up by two runs using 5 mm dia electrode.
- Number of electrode consumed per Run = (731.04) / {(63.19 X 2)} = 6

Table 6: Summary Various Runs of SMAW

Weld Run no	Electrode Dia X Length(mm)	Electrodes consumed	Volt	Amps	Arc on Time	Power consumed KWH
Back Seam Root Run	3.15 x 450 3.15 x 450	12 12	34 34	150 150	8 min10 sec 8 min10 sec	1.11
Second Run Third Run	4.00 x 450 4.00 x 450	8 8	34 34	180 180	6 min 48 sec 6 min48 sec	1.11
Fourth Run Fifth Run	5.00 x 450 5.00 x 450	6 6	34 34	225 225	5 mm 27 sec 5 mm 27 sec	1.11

Total Arc on time =40 min 50 sec, Labour cost =Rs. 150 per day for 8 hours

- Total Power consumed =(1.11 X 3) =3.33 KWH =3.3 Units
- Labour cost with 60% duty cycle = {150 / (8 X 50)} X{ (40.83 / 0.6)} = Rs. 21.26
- Cost of Electrodes   Diameter 3.2 mm=24 @2.00= Rs.48.00
- Diameter   4 mm =16 @2.75= Rs.44.00,   Diameter 5mm =12 @4.60= Rs.55.20
- Total cost   Rs. 147.20, Cost of Power 3.33 units @ Rs. 4.00 =13.32
- Cost of labour =   21.26, Overhead (@300% of labour cost = 63.78
- Total Rs.   245.56 = $ 5.0

 GMAW Process is cheaper (30%) than SMAW process by Rs.75.90 ($ 1.5) per metre run

7. Conclusion

There is a challenge to expand cost effective welding practices in steel intensive construction sector in India. One of the major problems faced by the Indian steel industry today is creating new domestic markets for increased steel consumption. The *Institute for Steel Development and Growth* (INSDAG) has been formed to address the problem systematically. A lot need to be done in terms of welding infrastructure development for steel intensive construction. Development of medium and small-scale fabrication and welding houses located all over the country with state-of-the art equipments and offering quality service is a must for the wide spread development of steel intensive construction. The availability of Shear Studs and Stud Guns, and trained man power for the their operation is a basic pre requirement for success of composite construction in India.

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