Welding Productivity and Economy

by R. VENKATESAN*

Abstract

The welding group of the National Committee on Science and Technology (NCST) reports that in India, presently 95% of the total weld metal deposited is by Manual Metal Arc Welding (MMAW) using coated stick electrodes and forecasts that even after 10 years from now, this will remain at 90%.

In this context, this paper briefly explains some of the factors that will contribute for improving productivity and bring down the cost of welding by MMAW process.

1.0 Introduction

Welding, like any other manufacturing operation costs money. In general, the cost of welding is especially important when the cost itself is large or when it represents a significant proportion of the total cost of a project or contract or when expressed on an annual basis. Moreover, welding is directly related to other operations. In general fabrication, the single most important trade could be welding. Most of the other activities or operations can be considered as allied operations as given below :

(i) Preparation of the material for welding:—this involves operations like marking, shearing, cutting, machining, gas cutting etc.

(ii) Setting-up the components for welding:—using jigs, fixtures, positioners, manipulators etc.

(iii) Tack welding the components to be welded:—this may involve assembly, cleaning the fusion faces by grinding etc.

(iv) Actual welding:

(v) After welding, subsequent mechanical operation—this may include dressing the welds, chipping, grinding, machining etc.

(vi) Heat treatment of the weld:

(vii) Inspection of the welds:—Visual, destructive and non-destructive testing.

Hence, it can be said that a fabrication shop functions with welding as the predominant operation and all the other activities are allied ones or subsidiary to welding.

If welding is the main-core operation of fabrication, then the productivity of any fabrication shop is directly affected by the productivity of welding operation; hence, the importance of welding productivity.

We are to-day employing many welding practices like manual arc welding, semi-automatic and automatic submerged arc welding, semi-automatic CO_2 Welding, TIG welding, electroslag welding, etc. But among all these practices, manual arc welding is one most widely employed.

In India, manual metal arc welding using coated stick electrodes accounted for more than 95 per cent of the total weld metal deposited, while in advanced countries, the ratio did not exceed 70 to 80 per cent. Even, ten years later, according to the report of the

* Industrial Engineer, Bharat Heavy Electricals Ltd. Tiruchirapalli. Paper presented at National Welding Seminar 1977.

welding group of the National Committee on Science and Technology (NCST) this ratio would remain at 90 per cent. Hence the emphasis of this paper will be mostly on manual metal arc welding.

2.0 Ways and means of increasing welding productivity

The productivity in welding or increasing of it, is in the hands of many people in an organisation. Some of those who vitally contribute are the designer, the welder, the shop engineer and the welding technologists.

3.0. Weld Design

3.1. Before we think of improving welding productivity, the first step could be to consider whether the welding or the joint itself is necessary. We have come across cases where a joint can be eliminated by using operations like bending, pressing and rolling.

3.2. Joints can be kept as few as possible by using standard rolled sections like the I, T and L, sections.

3.3. The designer should design the joint so that the joint requires the minimum amount of weld metal. An unnecessary increase in the fillet size from 6 mm to 8 mm can cause 58% extra consumption of electrodes and also cause a consequent increase in the labour costs. It is based upon this principle of minimum weld metal that the butt joints of higher thickness are designed as 'K' welds, 'U' welds, etc.

3.4. The designer should compute the weld sizes very correctly depending upon the load the joint is to carry. There may be many parts in machines that are lightly loaded or not loaded at all and it may be wasteful to deposit full strength welds on these parts. Careful analysis at the design stage itself, may reveal that not in all places the full weld is necessary. In many places, it may be sufficient if skip or intermittent weld is called for.

3.5. Wherever possible, subject to the minimum weld metal concept, the designer may call for the same type of welds throughout the job. This reduces the number of welding procedures, sequences, frequent changes etc.

4.0. The selection of the right type of electrode

4.1. Weld metal is an expensive material. While mild steel costs Rs. 1950/- to Rs. 2300/- per tonne in India, mild steel weld metal costs anything between Rs, 12,200/- and Rs. 16, 800/- per tonne. In Table No. 1, four types of mild steel electrodes have been listed which have Deposition Efficiency (DE) ranging from 85% to 160%, cost of weld metal deposited by 1000 pieces and the prices of the 1000 pieces of electrodes (These are approximate prices during 1976).

4.2. Deposition Efficiency is defined as the ratio of the weight of deposited metal to the net weight of the electrodes consumed exclusive of stub ends.

4.3. To achieve maximum welding productivity or, in other words, to reduce welding costs, it is not sufficient to judge the economics of an electrode merely from the price list. It can be seen from the Table No. 1, that while the price per 1000 pieces of item number: 3 is 79% more than that of item number: 1. the cost of weld metal is only 38% more than that of item number: 1, Similiarly, item number: 4 is more than 125% costly than item number: 1 based on price list, but its weld metal costs only 20% more than that of item no: 1. Also, item number: 4 is more economical than item number: 3 even though it appears more expensive in the price list.

4.4. Hence, wherever possible, iron powder electrodes having higher deposition efficiency should be used. These electrodes contain an appreciable quantity of metal powder in the coating, such that the weight of the resulting deposit is more than that of the core wire melted.

4.5. When we think of increasing welding productivity by reducing the labour and overhead costs (LOC's), iron powder electrodes work out to be more favourable. The LOC's per kg. of weld metal are calculated from the melting time per electrode, arc time required to deposit 1 Kg. of weld metal, weld time factor or arc time factor and LOC's per hour. Assuming LOC's as Rs. 4/- per hour, and the arc time factor as 2.4 the values for the four electrodes have been calculated and given in the column number: 5 of Table-2. The total cost of weld metal have been given in the last column.

Table 1. Weld Metal cost for different types of electrodes

Item No.	Electrode Type	DE %	Price for 1000 nos. Rs.	Weld Metal for 1000 pieces Kg	Cost of Weld Metal Rs./Kg
1.	General purpose Rutile	85	410	33.5	12.25
2.	Low Hydrogen Iron Powder	115	680	45.0	15.10
3.	Rutile Iron Powder	110	730	43.5	16.80
4.	Rutile Iron Powder	160	920	62.5	14.70

All electrodes are 4 mm ϕ and 450mm long—Stub thrown away is 50 mm.

Table 2. Total Weld Metal costs of different electrode types

Item No.	Electrode Type	Melting Time per Electrode Mins.	Matl. Cost of Weld Metal Rs./Kg,	LOC's of Weld Metal Rs./Kg.	Total Cost of Weld Metal Rs./Kg.
1.	General Purpose Rutile	1.71	12.25	7.6	19.85
2.	Low Hydrogen Iron Powder	1.70	15.10	6.1	21.20
3.	Rutile-Iron Powder	1.74	16.80	6.6	23.40
4.	Rutile-Iron Powder	1.57	14.70	4.0	18.70

Arc Time Factor or Weld Time Factor is defined as the ratio of Arc Time to Total Welding Time.

4.6. The fact that item number: 4. which is the most expensive electrode in the price list, works out most economical may seem astonishing. There are further advantages in using such high deposition efficiency electrodes. Suppose a fabricating shop employs 100 welders each of whom consumes 100 pieces of item number: 1 in an 8 hour shift. This means that 335 Kgs. of weld metal are deposited in a shift to maintain the production schedule. If the shop changes over to item no. 3, only 77 welders would be required to give this output. If it changes over to 4, only 54 welders need be employed. Fewer welders means fewer welding machines, maintenance, a saving in floor space, fewer welding accessories and a smaller electric load etc.

5.0. Stubs thrown away

In discussing the productivity of manual arc welding, one must consider the question of stubs thrown away. It is always assumed that the electrode stub which is discarded is not larger than 50 mm. In actual practice, one observes long lengths of stubs 10 to 150 mm or even half burnt electrodes thrown away. A possible cause is that the welders are inclined to use high currents to get faster output and to ensure deep penetration. With such high currents, the conventional electrode gets prematurely overheated. Iron powder electrodes can take very big currents (Table No. 1; 190 amp. for item no. 3 and 220 amp. for item number: 4. as compared to 170 amp. for item number: 1) and give faster output thereby minimising rejection of long stubs.

Careful control of the length of discarded electrode stubs will have its effect on productivity. Table ; 3 given below illustrates the rise in cost when standard length of 50 mm stub length is exceeded.

Table 3. Cost Per Kg. of deposited metal in rupees

Cost Item	Length of the Stub thrown away			
	50 mm	100 mm	150 mm	200 mm
Labour	3.60	4.32	5.04	6.07
Overhead	3.60	4.32	5.04	6.07
Power	0.44	0.44	0.54	0.44
Electrode	14.70	17.64	20.58	24.99
	22.34	26.72	31.10	37.57

Assumptions :
Electrode : ϕ 6.3-450 mm long
DE : 110%
Arc Time Factor : 2.4
Cost of 1000 electrodes : Rs. 1470/-

Generally speaking, the labour costs per Kg. deposited rises when stub end sizes increase. This is due to the reduced operator factor and greater number of interruptions for changing electrodes. Electrode cost increases in proportion to the amount of stub end waste.

6.0. Largest Size of Electrode to be Used

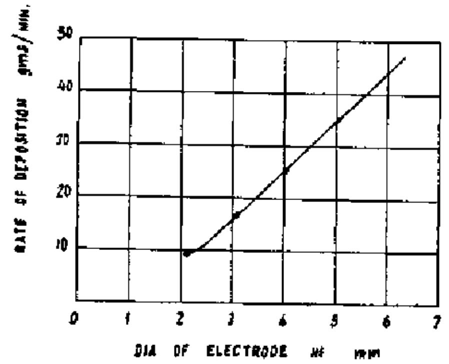
6.1. The diameter of the electrode used has a great bearing on productivity. The time of fusion of the electrode or the arcing time depends very much on this.

Table No. 4 below gives, at rated currents, the deposition rates of basic coated electrodes of different diameter. The increase in deposition rate with an increase in the dia of electrode is shown in the graph :

Table 4. Rate of deposition of electrodes in different diameters

Diameter of Electrode (mm)	Rate of Deposition Gm/Arc Minute (average)
2.00	8.40
2.50	11.04
3.15	17.85
4.00	25.44
5.00	35.10
6.30	42.76

DIA OF ELECTRODE Vs RATE OF DEPOSITION



6.2. The following Table No. 5 shows how much arc time is gained (or lost) by using a larger (or smaller) diameter electrode. The figures along the diagonal read 1.00. All the figures above the diagonal are more than 1, and all the figures below the diagonal less than 1.

Let us take an example :

Take the case of 4.00 mm dia electrode. Looking at column. 4, row 4, we find the value to be 1.00. The values above this are 1.425, 2.305, 3.028 respectively. This means that instead of 4.00 mm. dia electrode, if we use dia 3.15 electrode, the time will increase by 42%. If a 2.5 mm electrode is used instead of 4.00 mm. electrode, the time will increase by 130%.

On reading below the line, instead of using 4.00 mm electrode if we use 5.00 mm electrode, the time will be only 72.5% or a saving of nearly 28%.

6.3. A further advantage resulting from a change to large diameter electrodes is the reduction in time (lesser arc time factor) spent in replacing the stub ends with a fresh electrode, as shown in Table—6 below where a typical rutile electrode is considered.

7.0. Deep Penetration Electrode

The productivity of a deep penetration electrode is derived from the fact that a butt joint can be made in plates upto 12 mm. thickness with square edges by depositing one pass on each side. The need for edge preparation is eliminated. Square edges ensure easy and accurate fit-up and root gap. Very little weld metal is required to fill the gap since a large proportion of the welded joint is made-up of the fused parent metal. Also back gouging operation is dispensed with.

Table 5

Diameter of Electrode mm	Diameter of Electrode—mm					
	2.00	2.50	3.15	4.00	5.00	6.30
2.00	**1.00**	1.314	2.125	3.028	4.179	5.090
2.50	0.760	**1.00**	1.617	2.305	3.179	3.873
3.15	0.470	0.618	**1.00**	1.425	1.966	2.395
4.00	0.330	0.434	0.701	**1.00**	1.379	1.680
5.00	0.238	0.314	0.508	0.725	**1.00**	1.204
6.30	0.196	0.258	0.417	0.595	0.820	**1.00**

Table 6

Electrode Dia mm	Electrode Length mm	No. of Electrode changes per Kg. of deposited Weld Metal (DE 110%)
3.15	450	36
4.00	450	24
5.00	450	14
6.30	450	11

The type of electrode used in India has an extremely heavy coating which consists mainly of rutile iron powder and cellulose. It is made 350 mm. long. It can carry very high current :

3.15 mm. —170 amp.
4.00 mm. —225 amp.
5.00 mm. —300 amp.

The penetrating arc lifts up all the slag inclusions and gives a smooth weld metal with complete fusion. The table given below gives the cost comparison between a conventional rutile and deep penetration electrode in making one metre long butt joint in 12 mm. thick plate.

8.0. Welding Position

The size of the molten weld pool dictates the current that can be used for position welding. Thus, while the maximum current which can be used in down hand welding position is limited generally only by the material and its thickness, the maximum currents usable for positional welding is severely limited by the effect of gravity on the molten pool.

Most applications can be positioned with the weld at the down hand position, and the costs of manipulating or positioning the equipment are easily cancelled out by the considerable savings that result from the down hand welding.

An authoritative welding handbook says that if the welding costs are taken as 100% in the flat position, they rise to 165% in the horizontal and to 294% in the overhead positions.

9.0. Operator Factor

9.1. The Operator Factor represents that percentage of the work day spent in actual welding (Arc Time).

Arc Time is known as the duration (usually expressed in minutes) the arc is maintained in making an arc weld.

The percentage of Arc Time fundamentally controls the economy of the deposition of weld metal. However important a welder's other duties may appear to be, if no arc exists, no filler metal is being deposited. The effective use of the workman's productivity time is one of the greatest factors in the total cost of the finished unit. The Operator Factor therefore applies to all operations in welding where production depends on the productivity capacity of the welder or the welding machine operator.

Table 7. Cost Comparison of Rutile Vs. Deep Penetration Electrodes
BUTT JOINT: Plate Thickness : 12 mm
Joint length : 1000 mm

Cost Items	Rutile Electrode Edge Preparation : 60° 'V' Root Gap 2 mm			Deep Penetration Electrode Edge Preparation : Square Root Gap : 2.5 mm		
	I Side	II Side	Cost Rs.	I Side	II Side	Cost Rs.
Electrode Cost Root Run	6.5 Nos. ϕ 3.15 mm	—	1.82	—	—	—
Electrode Cost Filling-up and sealing run	14.5 Nos. ϕ 5.0 mm	4.5 Nos. ϕ 4.0 mm	11.50	4.5 Nos. ϕ 4.00 mm	4.5 Nos. ϕ 4.00 mm	6.57
Labour and Overhead Cost	50 mins.	12 mins.	4.00	9.0 mins	9.0 mins	1.20
Labour and Overhead Costs for Gouging out the root with pneumatic chisel	—	18 mins	0.90	—	—	—
Power Cost	—	—	0.28	—	—	0.20
Cost of compressor air	—	7 m^3	0.50	—	—	—
Total Cost per metre of Joint	—	—	19.00	—	—	7.97

Note :—The Table is prepared based on the following data :

Price for 1000 Nos.
(a) Rutile electrode DE 82%
(b) Deep Penetration electrode DE: 150%
Stub thrown away : 50 mm
Arc Time Factor : 1.5

ϕ 5—450 long Rs. 630/-
ϕ 4—450 long Rs. 410/-
ϕ 3.15—450 long Rs. 260/-
ϕ 4—350 long Rs. 730/-

9.2. Arc Time may vary from as low as 10% of the welder's work hours to as high as 50% depending on the type of work and handling facilities. The average figure used for a moderately heavy and large work is approximately 40% of the welder's work hours.

9.3. Every effort should be made to increase the operator factor. The welder's performance determines the appearance and quality of the weld ; therefore, every obstacle hampering the welder should be removed. Work should be planned and positioned to minimise physical strain and ensure maximum comfort and safety.

9.4. It may be economical to provide the welder with a helper who can setup the jobs for him. Every operation the welder has to perform, apart from actual welding, reduces the arc time and this naturally reduces the operator factor. It is not unusual for a welder to spend 50% of his time setting up. If his production rate is 10 units per hour, he may spend 3 minutes welding. If he is provided with a helper and an additional jig, his production is nearly doubled. The helper sets up while he is welding and the welder merely moves from jig to jig. Thus it is possible to almost double the production with only an extra jig and one helper and at the same time, reduce costs simultaneously.

10.0. The Role Played by Jigs, Fixtures and Positioners

The use of jigs or positioners enable the job to be done in down hand position welding. Hence, large diameter electrodes and automatic welding processes for getting higher deposition rates can be operated.

In addition, down hand welding with the use of manipulators or positioners calls for less skill on the part of the operator. It is also less fatiguing.

Because of the above reasons, welds of consistently better quality can be made.

Jigs and fixtures enable the shops to make quick and accurate fit-up. This enables the welder to maintain a high arc time factor.

Jigs and fixtures also help in minimising distortion and the subsequent rework.

11.0. Operator's Efficiency

To achieve very high productivity, the welder should be given every facility that can increase his efficiency and decrease fatigue. The above should include his safety requirements also. Provision of ammeters, etc. on the machine enables the operator to maintain accurate working condition. Whenever possible, templates should be made available to the operator to maintain accurate dimensions and weld sizes.

12.0. Conclusion

Cost figures discussed above are only illustrative and direct cost. Considering the associated indirect costs the saving would be much higher. Besides, there are many intangible benefits like reduction in manufacturing cycle time etc.

An organised multi pronged attack on the above factors will lead to a higher productivity and bring down the cost of welding operation.

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