INVESTIGATION INTO OPTIMAL MECHANICAL PROPERTIES FOR ARC WELDED BUTT JOINTS

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Abstract : *An attempt has been made to predict the optimal mechanical properties of welded industrial steel specimens through the use of standard statistical techniques of regression analysis. The experimental results have revealed the weldments as sound as base material for industrial applications.*

Notations :

D	*Ultimate tensile strength, MPa*
F	*Hardness on heat affected zone, Rockwell-B*
H	*Heat input per mm length of weld, kJ/mm*
Q	*Heat input rate, kJ/sec.*

INTRODUCTION

The mechanical properties of welded joints depend on several factors including energy input. During welding, heat is applied to the weldment and the cooling-rate influences the mechanical parameters to some extent.

The strength of the welded joints is the fundamental property to the service reliability of the weldments and hence the present work has been undertaken to study the influence of heat input in arc welded joints, Accordingly the welding parameters determined to reflect the heat conditions in the weldments are heat input rate and heat input per mm length of Weld. An attempt has thus been made to predict the optimal mechanical parameters with respect to welding parameters.

In the present investigation the mechanical properties viz., ultimate tensile strength and hardness on heat affected zone have been experimentally determined. It is established[1-4] that welding heat produces maximum hardness on the heat affected zone. Hence, in the present programme, hardness of weldments has been considered to be that on the heat affectad zone only. Welding parameters during welding have been obtained from the easily available welding shop-floor data.

EXPERIMENTAL PROCEDURE

Materials

Thirty-one specimens (750mm x 600mm) fabricated as shown in Table I from hot rolled structural steel plates (carbon varying from 0.15% to 0.22% – Table II) of 10mm and 12mm thickness and welded by industrial welders have been used in the studies.

Mechanical tests

Conventional mechanical tests were carried out on test pieces cut out from each welded specimen to ascertain the strength of the joint.

Tensile specimens were tested on a Universal Testing Machine and hardness test was carried out in a Rockwell Hardness Testing Machine. Table III shows the test results.

Welding Procedure

The samples were welded by industrial welders using mild steel electrodes at 350A (ac) through welding transformer. The welding

TABLE - I : Joint Preparation

Sample no.	Root opening (= Root face) (mm)	Bevel angle (rad.)	Plate thickness (mm)
S-1.1	0	1.04(a)	12
S-1.2	1.5	1.04	12
S-1.3	2.5	1.04	12
S-1.4	0	1.22(b)	12
S-1.5	1.5	1.22	12
S-1.6	2.5	1.22	12
S-1.7	2.5	1.22	12
S-2.1	0	1.04	10
S-2.2	1.5	1.04	10
S-2.3	2.5	1.04	10
S-2.4	0	1.22	10
S-2.5	1.5	1.22	10
S-2.6	2.5	1.22	10
S-2.7	0	1.04	10
S-2.8	1.5	1.04	10
S-2.9	2.5	1.04	10
S-2.10	0	1.22	10
S-2.11	1.5	1.22	10
S-2.12	2.5	1.22	10
S-3.1	0	1.04	12
S-3.2	1.5	1.04	12
S-3.3	2.5	1.04	12
S-3.4	0	1.22	12
S-3.5	1.5	1.22	12
S-3.6	2.5	1.22	12
S-3.7	0	1.04	12
S-3.8	1.5	1.04	12
S-3.9	2.5	1.04	12
S-3.10	0	1.22	12
S-3.11	1.5	1.22	12
S-3.12	2.5	1.22	12

(a) 1.04 rad. = 60^0 (b) 1.22 rad. = 70^0
Length of weld = 750 mm.

TABLE - II : Chemical composition of steels used

Sample batch no.	% Carbon	% Manganese	% Sulphur	% Phosphorous	% Silicon
S-1	0.15	0.80	0.033	0.020	0.150
S-2	0.17	0.75	0.027	0.012	0.047
S-3	0.22	0.89	0.019	0.021	0.024

TABLE - III : Mechanical test results

Sample no.	Ultimate tensile Strength (MPa)	Hardness (Rockwell-B) on heat affected zone
S-1.1	429.16	99.0
S-1.2	451.42	99.0
S-1.3	429.51	93.0
S-1.4	447.33	99.5
S-1.5	442.84	99.0
S-1.6	443.36	97.0
S-1.7	448.31	97.0
S-2.1	474.60	107.0
S-2.2	476.36	100.0
S-2.3	435.37	92.0
S-2.4	488.99	93.0
S-2.5	488.22	91.5
S-2.6	446.27	99.0
S-2.7	481.54	108.0
S-2.8	492.01	101.5
S-2.9	446.84	92.0
S-2.10	424.76	91.5
S-2.11	432.03	90.0
S-2.12	471.60	98.0
S-3.1	389.64	96.0
S-3.2	492.16	111.0
S-3.3	434.02	109.5
S-3.4	507.28	101.0
S-3.5	521.87	101.0
S-3.6	453.91	97.0
S-3.7	473.64	96.5
S-3.8	551.73	109.0
S-3.9	492.06	107.0
S-3.10	443.61	100.0
S-3.11	532.54	102.0
S-3.12	571.07	98.0

In all cases fracture has taken place within the base metal during tensile testing.

TABLE - IV : Welding Parameters		
Sample no.	Heat input rate Q (KJ/sec.)	Heat input per mm. length of weld H (KJ/mm)
S-1.1	5.39	13.15
S-1.2	5.48	10.52
S-1.3	5.69	11.02
S-1.4	5.77	14.07
S-1.5	5.60	8.97
S-1.6	5.60	11.81
S-1.7	5.64	11.57
S-2.1	5.27	7.06
S-2.2	5.27	9.02
S-2.3	5.23	7.23
S-2.4	5.35	7.71
S-2.5	5.31	7.59
S-2.6	5.02	8.54
S-2.7	5.35	7.38
S-2.8	5.35	9.18
S-2.9	5.27	7.31
S-2.10	5.27	7.54
S-2.11	5.31	7.44
S-2.12	5.06	8.41
S-3.1	5.35	9.25
S-3.2	5.35	8.85
S-3.3	5.14	8.56
S-3.4	5.39	10.07
S-3.5	5.52	8.23
S-3.6	5.31	9.10
S-3.7	5.35	9.35
S-3.8	5.35	8.55
S-3.9	5.10	8.30
S-3.10	5.31	9.87
S-3.11	5.56	8.42
S-3.12	5.52	9.52

parameters obtained from shop-floor welding data are shown in Table IV.

RESULTS AND DISCUSSIONS

Computational procedure to establish correlations

The best-fit equations to correlate the mechanical parameters and the welding parameters are obtained using standard statistical techniques of regression analysis. The experimental data are analysed by the least squares regressicn technique. Conventional polynomial type of equations between mechanical properties (D and F) and the welding parametars (H and Q) arc selected.

The analysis were performed with the help of a standard statistical package programme, BASIS (Burroughs Advanced Statistical Inquiry System), using Burroughs 6738 computer.

Prediction equations – the applications

The prediction equations obtained through regression analysis and given in Table V can bo used to predict the optimal values of the mechanical properties for minimal values of the welding parameters within the range studied. Alternatively one can predict a value of the welding parameter for a specified value of the mechanical parameter, within the range studied, from the corresponding prediction equation. This second application of the prediction equation is, in effect, the reverse of the first. Best fit

TABLE - V : Prediction Equations

Mechanical properties vs. welding parameters	Sample batch no.	Equations	
F Vs. Q		$F = 1521.11174 - 504{,}91821\ Q + 44.75244 Q^2$	... (I)
D Vs. H	S-1	$D = 497.92922 - 9.24552\ H + 0.36915\ H^2$	... (IIa)
F Vs. H		$F = 156.86630 - 10.67432\ H + 0.47160\ H^2$	... (IIb)
D Vs. Q		$D = 33588.24360 - 12854.34465\ Q + 1246.08972\ Q^2$	... (IIIa)
F Vs. Q	S-2	$F = 5560.51291 - 2107.20376\ Q + 203.06470\ Q^2$	... (IIIb)
D Vs. H		$D = 983.39742 - 140.60962\ H + 9{\cdot}33740\ H^2$	... (IVa)
F Vs. H		$F = 575{\cdot}69356 - 120.52586\ H + 7.52641\ H^2$	... (IVb)
D Vs. Q		$D = 22066.56678 - 8301.21421\ Q + 797.20274\ Q^2$	... (Va)
F Vs. Q	S-3	$F = 1777.47998 - 612.14367\ Q + 55.86127\ Q^2$	... (Vb)
D Vs. H		$D = 4681.06662 - 909.03239\ H + 49.02875\ H^2$	... (VIa)
F Vs. H		$F = 351.26063 - 5037103\ H + 2{\cdot}51310\ H^2$	... (VIb)

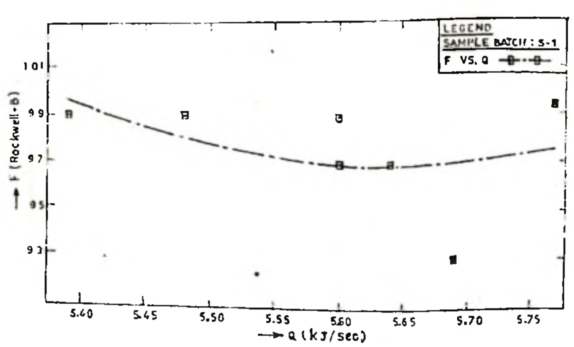

Fig. 1 : Hardness on heat affected zone (F) Vs. heat input rate (Q)

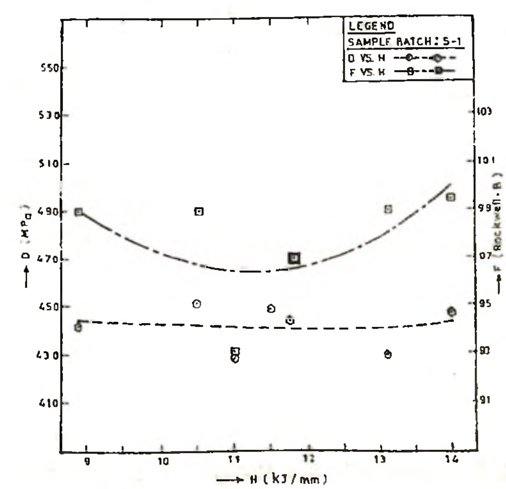

Fig. 2 : Ultimate tensile strength (D) & Hardness on heat affected zone (F) Vs. heat input per unit length of weld (H)

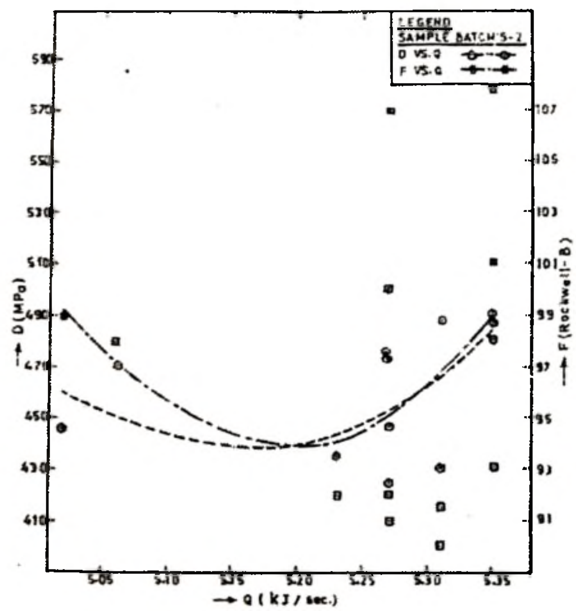

Fig. 3 : Ultimate tensile strength (D) & hardness on heat affected zone (F) Vs. heat input rate (Q)

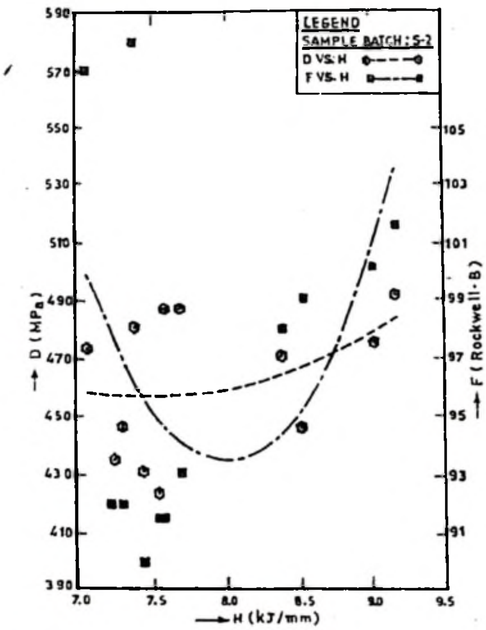

Fig. 4 : Ultimate tensile strength (D) & hardness on heat affected zone (F) Vs. heat input per unit length of weld (H)

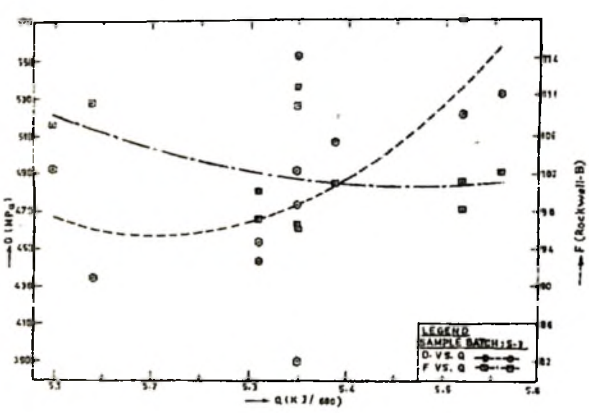

Fig. 5 : Ultimate tensile strength (D) & Hardness on heat affected zone (F) Vs. heat input rate (Q)

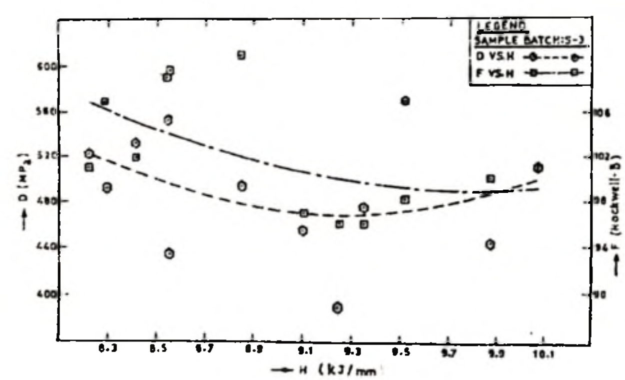

Fig. 6 : Ultimate tensile strength (D) & Hardness on heat affected zone (F) Vs. heat input per unit length of weld (H)

curves, based on prediction equations, are plotted and are shown in Fig. 1 to 6.

It is observed that in almost all the cases the mechanical property values decrease as the welding parameter values increase, upto a certain value, and then mechanical property values increase again as welding parameter values increase.

The optimal values of ultimate tensile strength (D) and hardness on heat affected zone (F) for least values of heat input rate (Q) and heat input per mm length of weld (H) have been calculated and these are shown in Tables VI to IX.

From Table VI, it is seen that there are some values of ultimate tensile strength (D) corresponding to the least values of heat input rate (Q) as illustrated in Figs 3 and 5; it is observed that the ultimate tensile strength tends to be minimal i.e. 438 MPa, while heat input rate is 5.18 KJ/Sec. Similarly from Table VIII, it is seen that there are some values of ultimate tensile strength (D) corresponding to the least values of heat input per mm length of weld (H) as illustrated in Figs. 2, 4 and 6; it is also observed that the ultimate tensile strength tends to be minimal i.e. 438 Mpa, while heat input per mm length of weld is 12.03 KJ/mm. It is to be noted that such minimal value of ultimate tensile strength (D) i.e. 438 MPa is in good agreement with that of the base metals (Table X), variation lying between 0.83% and 10.35%.

TABLE - VI : Optimal values of ultimate tensile strength (D) for least values of heat input rate (Q)

Sample batch no.	Ultimate tensile strength (D) (MPa)	Heat input rate (Q) (KJ/sec.)	Fig no.
S-2	438.00	5.18	3
S-3	455.00	5.20	5

TABLE - VII : Optimal values of hardness on heat affected zone (F) for least values of heat input rate (Q)

Sample batch no.	Hardness on heat affected zone (F) (Rockwell-B)	Heat input rate (Q) (KJ/sec.)	Fig no.
S-1	96.8	5.64	1
S-2	93.8	5.21	3
S-3	100.4	5.47	5

TABLE - VIII : Optimal values of ultimate tensile strength (D) for least values of heat input per unit length of weld (H)

Sample batch no.	Ultimate tensile strength (D) (MPa)	Heat input per unit length of weld (H) (KJ/mm)	Fig no.
S-1	438.00	12.03	2
S-2	457.00	7.36	4
S-3	466.00	9.27	6

TABLE - IX : Optimal values of hardness on heat affected zone (F) for least values of heat input per unit length of weld (H)

Sample batch no.	Hardness on heat affected zone (F) (Rockwell-B)	Heat input per unit length of weld (H) (KJ/mm)	Fig no.
S-1	96.4	11.27	2
S-2	93.5	8.05	4
S-3	98.8	9.84	6

From Table VII, it is seen that there are some values of hardness on heat affected zone tends to be minimal i.e. 93.8 (Rockwell-B), while heat input rate is 5.21 kj/sec.

Similarly from Table IX, it is seen that there are some values of hardness on heat affected zone (F.) corresponding to the least values of heat input rate (Q) as illustrated in

TABLE - X : Average values of mechanical properties of base metals

Sample batch no.	Ultimate tensile strength (MPa)	Hardness (Rockwell-B)
S-1	441.70	77.07
S-2	463.21	83.04
S-3	488.62	82.62

Figs. 1, 3 and 5; it is observed that the hardness on heat affected zone tends to be minimal i.e. 93.8 (Rockwell-B), while heat input rate is 5.21 kJ/sec. Similarly from Table IX. it is seen that there are some values of hardness on heat affected zone (F) corresponding to the least values of heat input per mm length of weld (H) as illustrated in Figs. 2, 4 and 6; it is also observed that the hardness on heat affected zone tends to be minimal i.e. 93.5 (Rockwell–B), while heat input per mm length of weld is 8.05 KJ/mm. It is also to be noted that such minimal values of hardness on heat affected zone (F) i.e. 93.8 (Rockwell–B) and 93.5 (Rockwell–B) are greater than that of the base metals (Table X).

CONCLUSION

Regression equations of the polynomial type were calculated to predict the mechanical properties obtained during welding. The prediction is for a particular value of the welding parameter within the range studied. These prediction equations are useful for establishing optimum mechanical properties (ultimate tensile strength and hardness on heat affected zone) at which the welding parameters (heat input rate and heat input per mm length of weld) are minimal. The findings also establish that the mechanical properties of weldments remain unaffected for minimal welding parameters i.e. weldments remain as sound as base material [5]. It should be noted that the prediction equations are valid only when the welding parameters being considered are within the limits of those investigated in the present study. All experiments were performed manually; however, the utmost care was taken to control the welding parameters.

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CORRIGENDUM

We regret an error under "AM-IIW Examinations : Summer Session, 2000" on page 66 of the April Issue of IWJ.

Please note that the examination will commence on 17th July, 2000 and not on 7th July, 2000.