A METHOD FOR ASSESSING THE TRANSFERABILITY OF ALUMINUM GMAW SET-UP PARAMETERS

AHMED EL-SAWY*

ABSTRACT

The transferability of aluminum GMAW parameters was assessed using statistical analyses which found binary correlation coefficients between the independent/dependent parameters of the welding system. The parameters have been arranged descendently according to their relative importance based on the values of correlation coefficients. The descending order of the independent parameters was used to perform a significant multiple-regression with the dependent parameters. The multiple correlation coefficients obtained by this method are very close to unity.

INTRODUCTION

GMAW is a well established process for aluminum joining. Most of the published work on the GMAW process has dwelled on the process technology and metallurgical aspects rather than process fundamentals, due to difficulties in visually assessing the characteristics of the process.

The weld bead geometry fluctuates when welds are made with different machines having different characteristics[1] . The main characteristics of GMAW system are the arc voltage, welding current, welding speed, wire feed rate, torch orientation angles, and both gas composition and flow rate. The output or the response of that system (i.e. the dependent parameters) are the weld bead geometry, structure, and mechanical properties of welded joint.

Scarse and complicated analytical relationships between dependent and independent parameters are reported in the literature. Some trials based on statistics are available in the literature [1-7] . These trials aim to assess the transferability of GMAW set-up parameters.

An investigation [5] was made to develop the relationships between weld heat input and strength characteristics of aluminum alloy 2219 (ASTM B209-65) welds. A multivariate regression analysis of experimental data was used. From this work, definite empirical formulae of multiple correlation coefficients of more than 0.79 were developed. These describe the interrelationships between the dependent tensile properties and the independent maximum

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*Associate Professor, Dept. of Mechanical Design and Production Engineering
Faculty of Engineering, Cairo University, Guiza, Egypt.

temperature reached during welding, and time at temperature. The maximum temperature and time at temperature were further expressed as functions of GMAW independent parameters. Other investigators [1,3-4] carried out a multiple stepwise regression analysis of the effects of GMAW parameters on 2219-T87, 6.25 mm thick aluminum alloy to determine the correlations between independent parameters and fourteen measured responses. The coefficient of determination was more than 50% for only four responses out of eighteen. The reliability and accuracy of these formulae are questionable due to the large number of parameters involved. No definite conclusions have been drawn by these investigators [1] regarding parameters which need to be duplicated for successful transfer of GMAW joints.

Welding engineers are in need of a reliable, rational means of selecting proper welding parameters. These are many independent and dependent parameters to be considered. So far, the selection of proper parameters has been made primarily on the basis of past experience and empirical data. It is very important to develop a scientific technique for this selection [1]. Statistical analysis is a useful tool for analysing experimental results. Unfortunately, little attention was paid to the physical meaning of the problems studied. Further studies need to be made of physical significance of regression equations.

OBJECTIVES

The objective of this work is to provide welding engineers with a system which could provide them with more information on the interrelationships between the independent and dependent parameters in aluminum GMAW system. It proposes a systematic approach of evaluating reliability of weld quality control. Moreover, statistics are used for analysing the results obtained in this work. In the light of the presented analysis of GMAW system, more attention would be paid to the physical meaning of the problem of assessing the technology of transferability of aluminum welds.

ANALYSIS OF GMAW SYSTEM

Fig.1 shows a flow chart for making a model with the independent and the responses of the GMAW system. The independent parameters are the welding voltage (i.e. arc length), current (i.e. wire feed rate), travel speed, shielding gas flow rate and the torch orientation angles. The system outputs (i.e. the responses or the dependent parameters) are the weld bead goemetry and structure; and the joint strength. The model gives an ideal procedure for controlling the weld quality. All welds can be made with satisfactory quality by selecting the appropriate joint parameters before welding, and control welding parameters during welding. This would assist welders in assessing the transferability of welding parameters, so that all welds made with different machines characteristics could have the same configuration and quality.

This model would also clarify to some extent the physical meaning which is often missing in statistical analysis.

EXPERIMENTAL PROGRAM

The experimental work presented in a previous work [7] by the author was used in this investigation. The analysis was made on one-pass GMAW, 1100 alloy (ASTM B209-65) aluminum welds, 3-mm thick. A screening

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of the experiments was performed based on 23-runs which involved two levels of cooling rate, as shown in Fig.1. The choice of three independent parameters permitted a statistical estimate of the significant interactions between both the independent and dependent parameters through the remaining tweenty degrees of freedom of the experiment.

The electrode orientation angles, arc length (i.e. the arc voltage) and both shielding gas composition and flow rate were kept constant during welding. It was expected that the cooling rate would have an effect on the shape and structure of the weld metal. Therefore, two cooling rates were chosen to clarify the effect of tooling during welding. All welds were run in random sequence in order to reduce the effect of external, uncontrolled variables. Eight dependent variables were monitored, viz., heat input, depth of penetration, reinforcement height and width, weld bead area, arc instability index, percent reduction of area, and finally the ultimate tensile strength.

STATISTICAL ANALYSIS

The correlation coefficients for all binary combinations of independent-dependent parameters are given in Table 2. The underlined values are those responses which have been determined to be correlated within 95% confidence limits. Any two parameters which have a correlation coefficient with an absolute value close to unity will produce a reliable relation.

However, the physical interpretation of the graph is not always apparent. Figs. 2-5 show the results obtained within 99% confidence limits. The correlation coefficients shown in Table 2 were used for multiple regression equations. The independent parameters which have correlation coefficients over 0.63 have been arranged descendently according to their relative effect. The independent parameters of lower correlation coefficients than 0.63 were neglected. The descending order of the independent parameters has been used to perform significant stepwise multiple regression with the dependent parameters[7-9].

RESULTS AND DISCUSSION

By comparing Tables 1 and 2, it is to be noted that the changes in the independent parameters produce greater changes in the dependent parameters. This indicates that the initial choice of experimental limits was effective in separating parameters responses. The underlined binary correlation coefficients values are those responses which have been determined to be correlated within 95% confidence. Perfect correlation is given by a correlation coefficient, R, of one. While random responses are given by correlation coefficients of zero. Figs.2-5 show the significant results obtained within 99% confidence limits.

Table 3 represents the multiple regression analyses results of the effects of aluminum GMAW parameters on weld responses. The multiple regression coefficients obtained are greater than 0.866.

Among the 66 binary correlation coefficients presented in Table 2, only 21 are correlated within 95% confidence limits[5]. The large number of correlated parameters demonstrate the complexity of the interactions during GMAW. However, the small number of strongly correlated parameters show that the effects of certain process changes, although real, are often of little or no significance. The discussion of each of the 21 correlations would be tedious and repetitive [5]. For example, the elements related to weld area are the depth of penetration, bead width, and reiforcement height. The fact that weld penetration has been found to be dependent primarily upon welding current [1] is not enough. Moreover, as shown in Fig.3, as the heat input increases the depth of penetration decreases, while both bead width and total weld bead area increase. Fig.2 shows also that weld bead area is affected by wire feed rate which represents simultaneously the welding current and melting rate (as shown in Fig.1). Also the welding speed represents one of the solidification parameters. Table 3 shows a multiple regression empirical relation of weld bead areas as a function of welding speed, heat input, bead width, wire feed rate, and reinforcement height, with multiple correlation coefficient of 0.96. The increase in reinforcement height is connected with the reduction in depth of penetration (Fig.4). The bead width increases with the increase of weld bead area (Fig.3). Since deposition rates constantly increase with current, reinforcement must rise sharply when the bead width remains constant or decreases, in order to accomodate the extra mass of deposited metal. These variations in bead dimensions (Fig.5), in conjunction with the bead structure, affect the percent reduction of area and ultimate tensile strength of the welded joint.

CONCLUSIONS

As a result of this parametric study, the correlation coefficients can be used as rational means for selecting and weighing the independent parameters in aluminum GMAW. The independent parameters can be arranged descendently, then according to their relative weight, significant multiple regression with the dependent parameters, of correlation coefficients close to one, can be performed.

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NOMENCLATURE

A_T = total fused area, mm^2
D = electrode diameter, mm
HAZ = heat-affected zone
HI = heat input, J/mm
I = average current, A
I_c = critical current for spray transfer, A
L = electrode extension, mm
M_{RP} = melting rate of DCRP, kg/h
R = correlation coefficient
%Red = percent reduction of area
T = temperature, °C
S = welding travelling speed, mm/s
UTS = ultimate tensile strength, N/mm^2
V = voltage, V
W = wire feed rate, mm/s
a,b &c = constants
c_p = specific heat, Kcal/kg.°C
h = reinforcement height, mm
p = depth of penetration, mm
ΔT = temperature difference, °C
ΔI = arc instability index, A
ρ = density, kg/m^3
η = thermal efficiency.

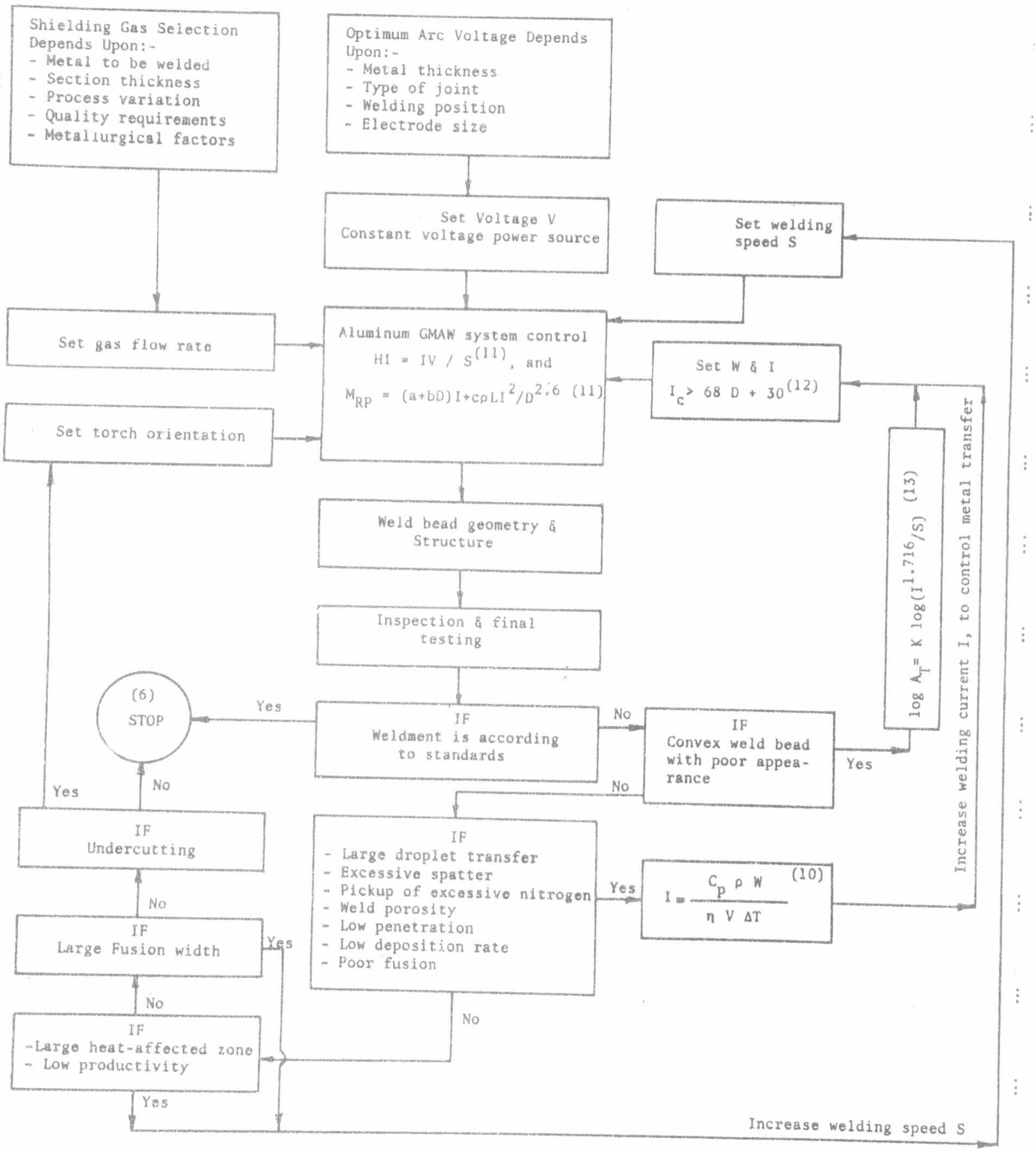

FIG. 1- ANALYSIS OF ALUMINUM GMAW SYSTEM & CONTROL OF WELD QUALITY

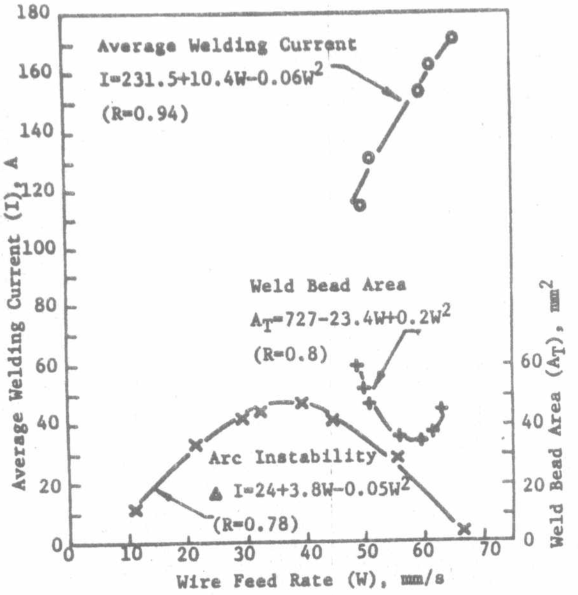

Fig.2-Average welding current (I), arc instability (Δ I), and weld bead area (A_T) vs wire feed rate (W).

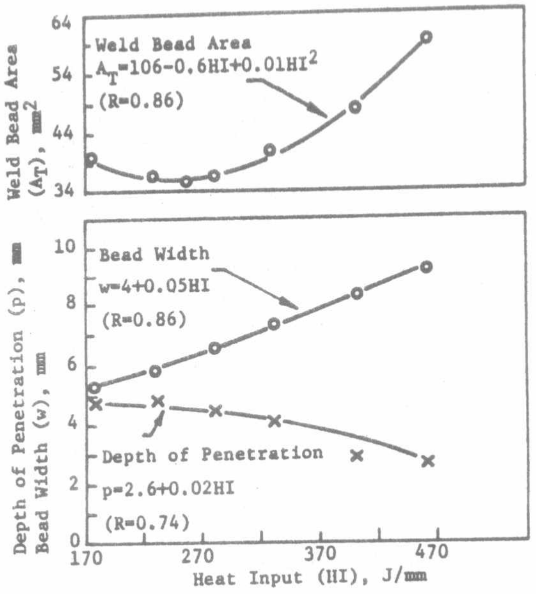

Fig.3-Depth of penetration (p), bead width (w), and weld bead area (A_T) vs heat input (HI).

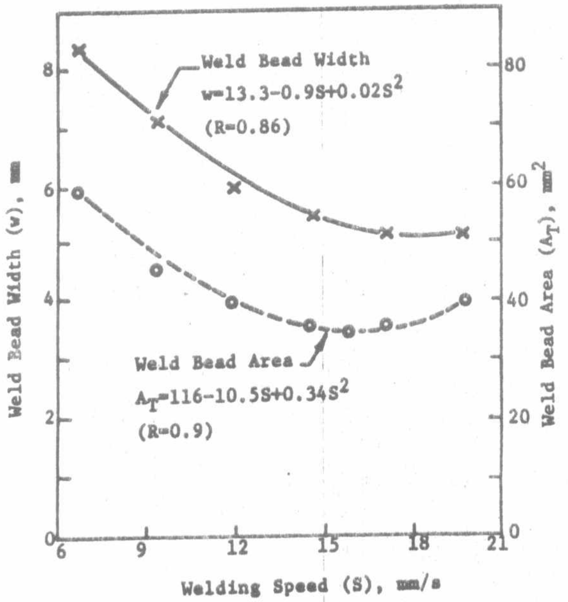

Fig.4-Weld bead width (w) and weld bead area (A_T) vs welding speed (S).

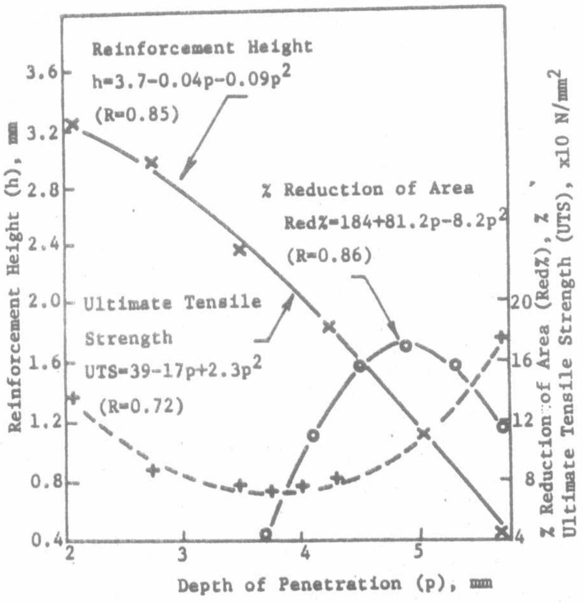

Fig.5-Reinforcement height (h), % reduction of area (Red%), and ultimate tensile strength (UTS) vs depth of penetration (p).

Table 3-Results of multiple regression analysis of the effects of aluminum GMAW parameters on weld responses

Multiple regression equations determined	Correlation Coefficient, R
$I = -62.25 + 2.9\ W + 0.07\ S + 2.0\ V$	0.934
$HI = 662 - 12.17\ V + 4.12\ I - 21.34\ S - 8.37\ W$	0.970
$p = 8.75 - 0.02\ HI - 0.18\ S + 1.29\ W - 0.012\ I$	0.875
$h = 4.88 - 0.76\ p + 0.122\ W + 0.0006\ HI - 0.048\ I$	0.899
$w = 6.12 - 0.08\ S + 0.006\ HI + 0.18\ h - 0.1\ p$	0.866
$A_T = -90.18 + 3.58\ S + 0.21\ HI + 5.97\ w - 0.22\ W + 6.02\ h$	0.960
$\Delta I = -105.19 - 0.87\ W + 1.98\ A_T + 8.53\ V - 0.15\ HI - 9.55\ p$	0.970
$Red\% = -13.3 + 1.9\ p + 2.4\ w - 4.2\ h + 0.1\ HI - 0.1\ A_T$	0.977
$UTS = -52.55 - 0.87\ h + 4.92\ p + 1.98\ V + 0.04\ Red\%$	0.915

Table 2-Correlation Coefficients

	Average Current (I)	Depth of Penetration (p)	Reinforcement Height (h)	Bead Width (w)	Weld Bead Area (A_T)	Arc Instability (ΔI)	Reduction of Area % (Red%)	Ultimate Tensile Strength (UTS)
Voltage (V)	0.57	0.11	0.14	0.34	0.43	0.51	0.14	0.67
Wire feed rate (W)	0.97	0.52	0.60	0.46	0.80	0.78	0.03	0.29
Welding Speed (S)	0.66	0.60	0.64	0.86	0.91	0.35	0.49	0.40
welding Current (I)	-	0.50	0.53	0.31	0.71	0.50	0.08	0.28
Heat Input (HI)	-	0.74	0.60	0.86	0.86	0.33	0.57	0.47
Depth of Penetration (p)	-	-	0.85	0.63	0.16	0.50	0.86	0.72
Reinforcement Height (H)	-	-	-	0.64	0.61	0.47	0.62	0.95
Bead Width (w)	-	-	-	-	0.83	0.19	0.67	0.28
Weld Bead Area (A_T)	-	-	-	-	-	0.75	0.52	0.35
Arc Instability (ΔI)	-	-	-	-	-	-	0.26	0.38
% Reduction of Area (Red%)	-	-	-	-	-	-	-	0.55

Table 1-Independent Parameters Choosen and Experimental Results Obtained

Independent Parameters Choseen								Experimental Results Obtained					
Trial No.	Voltage (V)	Wire Feed Rate (W), mm/s	Average Current (I), A	Arc Instability Index (ΔI), A	Travel Speed (S), mm/s	Cooling Rate Level	Heat Input (HI), J/mm	Penetration (p), mm	Height (h), mm	Width (w), mm	Total Fused Area (A_T), mm^2	Reduction of Area (%Red), %	Ultimate Tensile Strength (UTS), N/mm^2
1	22.0	54	150.0	40	13.0	H [a]	254.0	-	1.4	6.2	-	10.9	98.0
2	22.0	54	135.0	30	13.0	H	229.0	3.7	2.25	5.3	34.0	4.4	47.0
3	21.0	54	130.0	40	13.0	H	210.0	3.7	2.6	5.3	38.3	3.4	71.0
4	21.0	54	140.0	20	13.0	H	226.0	4.7	1.0	7.1	37.7	16.1	136.0
5	21.5	54	132.5	25	10.0	H	285.0	4.8	1.0	7.0	42.3	20.7	132.0
6	21.5	60	152.5	15	10.0	H	328.0	5.0	0.9	5.8	41.0	19.4	143.0
7	19.0	66	165.0	4	10.0	H	313.5	4.3	1.9	7.2	49.6	13.1	29.0
8	20.0	66	172.5	11	19.5	H	177.0	4.8	1.0	4.9	34.5	9.9	124.0
9	20.0	66	172.5	11	19.5	H	177.0	5.8	0.9	5.6	44.0	11.1	142.0
10	20.5	48	115.0	60	6.6	H	355.0	4.2	2.9	7.9	61.4	14.8	79.0
11	20.5	54	149.0	14	6.6	H	460.0	2.0	3.1	9.2	-	-	153.0
12	21.0	48	100.0	40	6.6	L [b]	316.0	2.1	2.1	7.2	-	-	-
13	21.5	60	115.0	50	6.6	L	372.0	5.1	1.0	8.2	54.9	12.2	127.0
14	25.5	54	110.0	40	10.0	L	280.5	4.0	2.2	7.3	49.4	2.6	62.0
15	19.5	60	150.0	4	10.0	L	292.5	4.4	1.3	9.2	56.6	17.2	140.0
16	19.5	60	150.0	4	10.0	L	292.5	4.6	2.0	9.2	68.8	10.9	128.0
17	22.5	42	95.0	50	4.7	L	455.0	6.0	1.9	9.0	75.2	20.6	159.0
18	21.0	54	135.0	6	13.0	L	218.0	5.5	0.9	7.3	46.8	20.9	159.0
19	25.0	60	165.0	14	13.0	L	317.0	4.8	1.8	8.3	66.2	18.5	85.0
20	22.0	54	120.0	30	13.0	L	203.0	4.6	1.8	5.7	46.7	30.5	144.0
21	20.5	60	165.0	14	13.0	L	260.0	4.4	1.4	6.0	51.0	22.1	125.0
22	20.5	60	159.5	3	19.5	L	168.0	-	-	-	-	12.6	126.0
23	20.5	66	130.0	4	19.5	L	137.0	4.8	1.6	5.9	46.2	18.2	152.0

a = High cooling rate   b = Low cooling rate