JSSC Guidance Report on Determination of Safe Preheating Conditions without Weld Cracks in Steel Structures†

Kunihiko SATOH*, Shigetomo MATSUI, Kohsuke HORIKAWA***, Kiyoshi BESSYO**** and Toshie OKUMURA*******

Abstract

The JSSC Study Group on Weld Cracking probed into the possible prevention of weld cracks that occur in welding of steel structures. In this connection, the group investigated about 100 instance of weld cracks in actual structures and studied how to select reasonable preheating conditions for the prevention of weld cracks.

As a result, cold cracks had accounted for more than 90% of the weld cracks in actual steel structures. In order to quantitatively determine concrete preheating conditions to avoid cold cracking, Pw-$(t_c)_{cr}$ criterion was extended to the practical application with consideration of practical welding procedure. It was able to develop a method wherein the optimum preheating temperature can be obtained with ease according to the actual conditions of welding.

1. Introduction

The studies for the determination of welding procedure to avoid weld cracking in steel constructions has been continued from 1969 in the Study Group on Weld Cracking of Society of Steel Construction of Japan. The main target of this group was to study actual instances of weld cracks that occured in the actual steel constructions and establish welding procedures to prevent such cracks. This brief report is now presented as a token of achievement by this study group.

Investigation of the actual instances of weld cracks disclosed that more than 90 precent of the crack trouble under study was cold crack[1]. Since preheating is the best remedy for the preventation of cold crack, this study group decided to establish a guide to reasonably select the optimum preherting condition befitting the weld structures of given material.

By applying the Pw criteria proposed by Ito and Bessyo[2], the study group indicated with actual instances the methods for determining the preheating temperature in consideration of actual conditions of preheating work[3]. The application of Pw criteria to curb the weld cracking susceptibility of steel plates, thereby providing a guide for selecting the steel plates was proposed by Tamura et. al[4].

2. Condition of Occurrence of Cracks in Actual Steel Constructions

With the aim of finding a clue to the study of the measures for the prevention of weld cracks, many weld crack instances were gathered for classification and study. The questionnaires were distributed on the fabricators of bridges and steel skeltons with the result that it was determined that more than 90

Members of Study Group on Weld Cracking

Chairman
K. Satoh, Osaka University
Secretary
M. Hayashi, Takadakiko Co., Ltd.
S. Matsui, Osaka University
K. Takemi, Nippon Kokan Kabushiki Kaisha
Member
H. Abe, Japan National Railways
K. Bessyo, Sumitomo Metal Industries Co., Ltd.
M. Harada, Japan Bridge Company Limited
H. Horikawa, Tokyo Metropolitan University
S. Hozumi, Katayama Iron Works Ltd.
T. Ishiguro, Mitsubishi Construction Co., Ltd.
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Y. Kuriyama, Ishikawajima-Harima Heavy Industries Co., Ltd.
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H. Nakamura, Nippon Steel Corporation
M. Natsume, Yokogawa Bridge Works, Limited
D. Okui, Harumoto Iron Works Ltd.
T. Okumura, The University of Tokyo
R. Sakurai, Matsuo Bridge Co., Ltd.
K. Sato, Kajima Construction Co., Ltd.
H. Tamura, Tokyo Institute of Technology
M. Yajima, Niigata University
S. Yajima, Hitachi Shipbuilding Engineering Co., Ltd.
S. Wakamiya, Komai Iron Works Co., Ltd.

† Received on July 30, 1973
* Professor
** Associate Professor, Dept. of Welding Engineering, Faculty of Engineering, Osaka University
*** Associate Professor, Dept. of Civil Engineering, Faculty of Engineering, Tokyo Metropolitan University
**** Central Technical Research Laboratory, Sumitomo Metal Industries Co., Ltd.
***** Professor, Dept. of Civil Engineering, Faculty of Engineering, University of Tokyo

Table 1. Presumed causes of weld cracks in steel constructions.

Presumed cause		Number of crack trouble	Typical problems	
Problems on material (steel plates and filler metal)		11(17%)	o Steel plate of which Ceq (P_{CM}) is extremly high o Lamination of steel plate	
Problems on procedure		20(31%)	o Problem on operation (ex. inadequate weld sequence) o Problem on accuracy of construction(fittness of members) o Problem on control (inadequate preheating)	
Problems on design	Detail of welded joint	10(16%)	o Welding of through plate o Patch welding	(Restraint is high)
	Problem on structure	20(31%)		
Others		3(5%)		

precent of the cracks reported was cold crack and the possible causes were shown in **Table 1.** Also it was discovered that problems involving material and design, along with that of procedure, should have to be given a serious study. It is suspected that the lack of proper preheating pursuant to the material and restraint condition might have had something to do with the cracks. Therefore, it is necessary to determine adequate preheating temperature and preheating procedure in consideration of the steel plates, welding procedure, plate thickness, restraint conditions, etc. for the prevention of cracks.

3. Existing Condition of Preheating in Welding of Bridges and Steel Skeltons

3-1 Questionnaires Concerning Preheating

Since it is presumed that a lot of methods have been adopted for preheating in the welding procedures of bridges and steel skeltons in particular according to the scale of structures, welding procedures or specification, the questionnaires were sent out to find out the actual condition of the preheating and its management in each fabricator. Given below is the summary of the findings.

a) Methods for determining preheating temperature

The methods for determining the preheating temperature vary according to the kinds of the steel constructions; but they can be classified according to specifications, office standard, past experiences and accomplishments, and procedure tests, etc.

Recommended as procedure test to determine the preheating temperature in the order of preference are:

1. y-groove restraint cracking test
2. Maximum hardness test
3. Commellel test

Of the above, y-groove restraint cracking test is rated high and it plays an important role in the determination of preheating temperature in Japan.

In the case of automatic welding, many replied that they do not employ preheating. It is considered that this is because they rule out the necessity, excluding exceptional cases, in the light of the large weld heat input.

b) Methods for preheating work.

Methods for preheating work differ slightly according to fabricators, but the results of the questionnaires were as shown in **Table 2.**

Table 2. Summary of preheating work.

Preheating temperature required	Length of preheating		Preheating side	Width of preheating	Period of preheating	Measuring position of preheating temperature	Measuring method of preheating temperature
	Welding procedure	Length of preheating					
50°C ~ 100°C	Manual welding Semi-automatic welding	Whole length of weld line	One side of welding part	50 ~ 100mm each on one side with weld line	Preheating prior to welding	30 ~ 50mm side from weld line	Thermo choak Surface thermometer
	(Submerged arc welding)	(Preheating ahead of welding head)					
100°C ~ 150°C	Manual welding Semi-automatic welding	Whole length of weld-line	One side or both side of welding part	50 ~ 100mm each on one side with weld line	Preheating prior to welding or continued preheating	30 ~ 50mm side from weld line	Thermo choak Surface thermometer
	(Submerged arc welding)	(Preheating ahead of welding head or Whole length of weld line)					

Preheating methods also differd according to the preheating temperatures required, but in the case of comparatively low preheating temperatures of 50～75℃ required, the welding parts were preheated prior to welding, suspending preheating during the welding. On the other hand, in the case of high preheating temperatures of 100～150℃ preheating of both sides of the welding part or continued preheating during the welding work was fairly common.

3-2 Actual Procedures of Preheating Work

Preheating work varies according to the objects to be preheated and the preheating temperatures, etc. In the case of low preheating temperatures, generally single nozzle gas burner is used while in the case of high preheating temperatures and the maintenance of interpass temperature is required, huge energy preheating device or preheating device or device whose temperature control is easy is used.

Photo. 1 shows an example of preheating procedure by single nozzle portable gas burner which is most widely used.

Photo. 2 shows a preheating device by multi nozzle gas burner, and it indicates an instance which is exclusively used for the preheating of heavily thick box girder.

Photo. 3 shows an instance of preheating procedure by an electric heater. The width of the heater is about 40 mm, the length about 1 m, bendable freely in the longitudinal direction. By connecting it with the body, it can be heated uniformly over a long welding length and automatic control of temperature is possible. The photo shows an example of application to a box girder with heaters adhered to the corner parts of the girder.

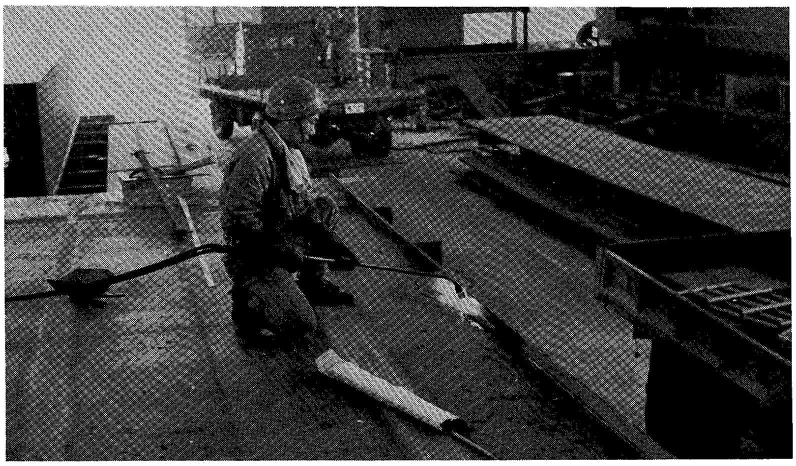


Photo. 1. Preheating work using single nozzle gas torch.

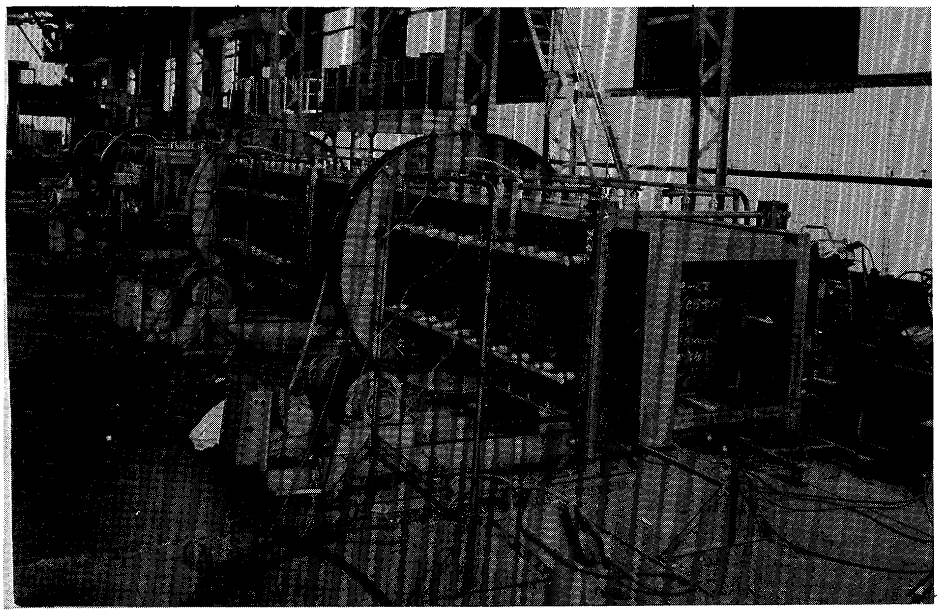


Photo. 2. Preheating units (multi nozzle gas torch) combined with rotative positioner.

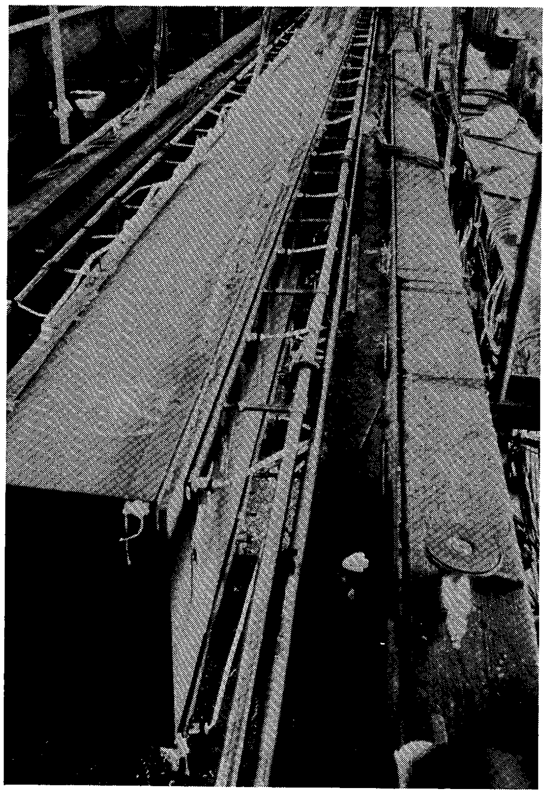


Photo. 3. Preheating work using electric heaters.

4. Selection of Preheaing Temperature without Weld-Cracks Based on Steel Plates, Hydrogen Content in Weld and Intensity of Restraint

4-1 Basic Thinking of Weld Crack Prevention

The occurrence of weld cracks in steel constructions is subject to the effect of various factors including the steel plates, filler material, welding method, welding procedures, atmospheric conditions, design of weld joints used, et al. To prevent the weld cracks, preheating is given but factors due to experience had a large role to play in the selection of preheating temperatures in welding procedures. As a clue to the selection of reasonable preheating temperatures, there is the Pw criteria proposed by Ito and Bessyo. The Pw criteria estimates[2] the occurrence of cracks from the relationship between the weld cracking parameter Pw comprising (1) chemical composition of steel plates P_{CM}, (2) hydrogen content in weld metal H and (3) intensity of restraint of weld joint K, which constitute vital factors connected with weld cracks, and the critical cooling time up to 100°C $(t_c)_{cr}$ at which cracks will not take place. In order to prevent the occurrence of cracks, it is necessary to select the condition of welding procedure in such a manner that the actual welding parts' cooling time $(t_c)_{ac}$ is larger than $(t_c)_{cr}$ shown in **Fig. 1.** **Fig. 2** shows a flow chart for applying this proposal to the weld crack prevention of steel structures.

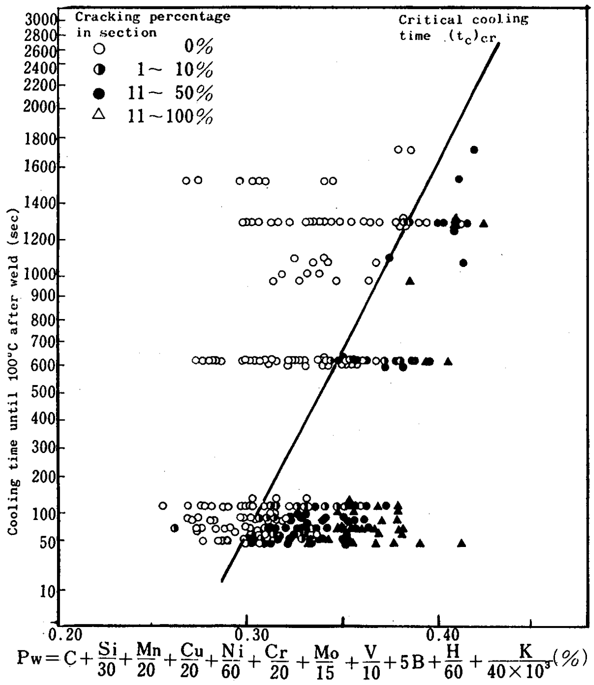


Fig. 1. Relation between Pw and cooling time until 100°C after weld.

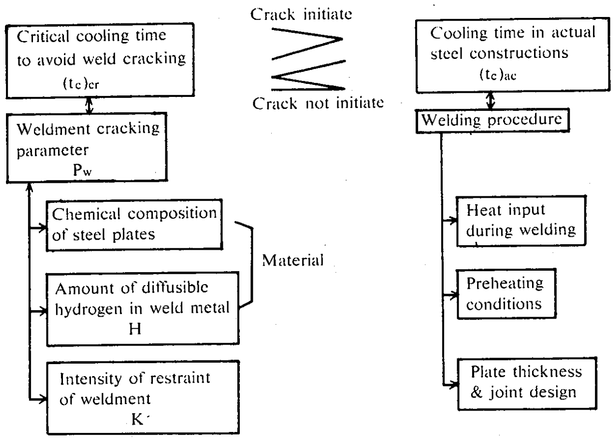


Fig. 2. Flow chart of basic procedure to aboid weld cracking in steel constructions.

$$P_w = P_{CM} + \frac{H}{60} + \frac{K}{40000}\ (\%)$$

$$P_{CM} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B\ (\%) \quad (1)$$

H: Diffusible hydrogen content in weld metal (cc/100g)
K: Intensity of restraint (kg/mm·mm)

4-2 Guide for Selecting Preheating Conditions for Preventing Weld Cracks

For the selection of the most reasonable preheating temperatures, it is desirable that the chemical composition of the steel plates P_{CM}, hydrogen content in the weld metal H and the intensity of restraint of the weld joint K are known and a method to determine the preheating temperature be adopted by calculating the Pw-values from their values. However, P_{CM}-value, H-value and K-value are variables. Therefore, to seek Pw-values in each case and control in such a manner that the preheating temperatures obtained from the Pw-values be observed correctly appear to further complicate the actual work.

It would be appropriete, therefore, that the control of the preheating temperatures suitable for the actual preheating work be made by grades of the steel plates as are currently adopted in the instruction books, and for plate thickness also by thickness classification in three stages or so like plate thickness below 25 mm, that above 25 mm and below 38 mm, and that above 38 mm and below 50 mm.

For this purpose, it is necessary to specify:

○ Control Standard of Steel Plates........ Limit of accepting
P_{CM}-values with steel plate standard and plate thickness

○ Control Standard of H-content........ Selection of welding rods, control of drying condition, control of leave-off time after drying, standard at high moisture

○ Control Standard of Intensity of Restraint.....Classification of the intensity of restraint of weld joints of actual structures

Since these standards are considered to vary according to each contractor each project, it is desirable that control standard be set about preheating temperatures for each project.

4-3 Factors Contained in Weld Cracking Parameter Pw

4-3-1 Chemical Composition of Steel Plates (P_{CM})

It is desirable to adopt the check analysis value, whenever possible, for the chemical composition values of steel plates, but for general purposes it is more convenient to set the accepting limit of P_{CM} values of the steel plate grades and also by their plate thickness.

The P_{CM}-values show a range of variations as shown in **Fig. 3** according to the ultimate strength level of steel. The actual P_{CM}-values of high strength steels now available on the market are more or less similar to, for instance, the maximum of HT60 and HT80, if shown by their plate thickness of **Fig. 4.** And also the maximum P_{CM}-value of specially quality controlled plates used for Nanko Bridge (Gervertras type bridge...center span 510 m) are shown in **Fig. 4**

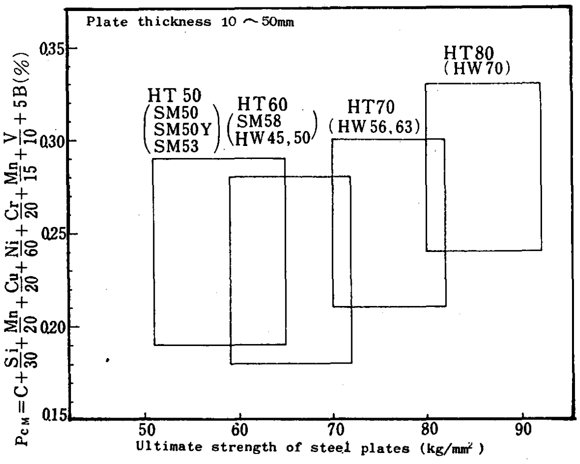


Fig. 3. Ultimate strength of steel plates versus P_{CM}-value.

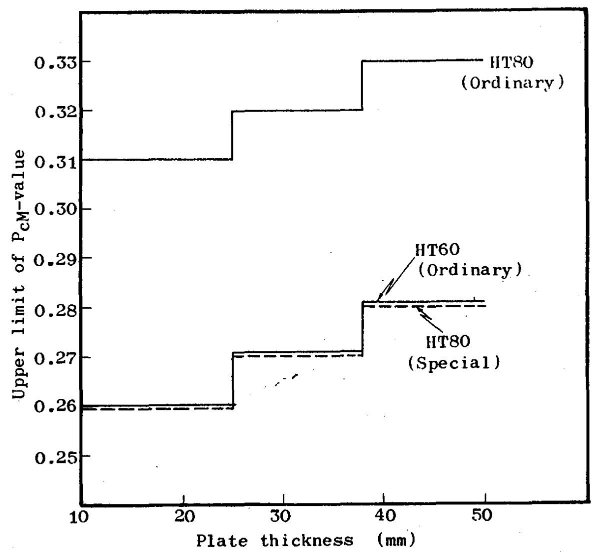


Fig. 4. One example of upper limits of P_{CM}-value of HT60 and HT80.

by dotted line.

4-3-2 Diffusible Hydrogen Content in Weld Metal

Although the diffusible hydrogen content in weld metal varies according to the drying condition, leave-off time after drying, temperature of welding atomosphere and moisture in addition to the brands of electrodes, generally it can be summed up by the values shown in **Table 3.**

4-3-3 Intensity of Restraint of Welded Joint

The welded joints in the actual steel structures are of complicate construction, and the calculation of their intensity of restraint is quite difficult. For this reason, actual measurement of intensity of restraint has taken place in various constructions. These values can be adjusted as shown in **Fig. 5,** and K-value, if taken to the tune of 40 times the plate thickness, is usually considered to be safe[5].

Table 3. Diffusible hydrogen content in weld metal.

Type of electrode Upper: JIS, WES Lower: ASTM	Cases using electrodes under normal control of drying and keeping	Cases using electrodes under high moisture or improper keeping after drying	Cases using extra low hydrogen electrodes
D 5016 E 7016	4.0 cc/100g	6.0 cc/100g	2.0 cc/100g
D 5816 E 9016	2.3	4.0	1.0
DK 7016 E 11016	1.6	2.5	1.0

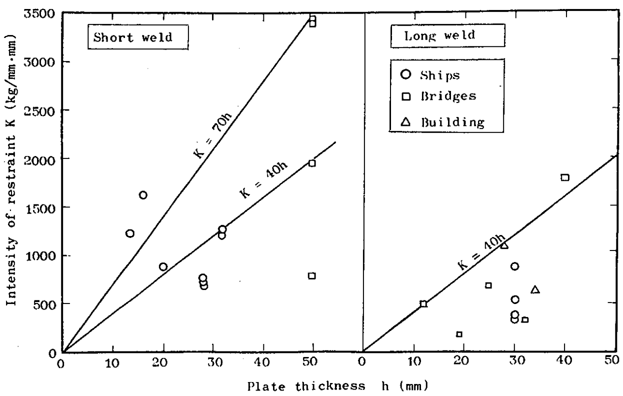


Fig. 5. Restraint intensity of weld joints in real structures.

4-4 Relation between Cooling Process and Preheating Conditions

The cooling process of the weld, as shown in **Table 4,** is largely affected by the weld heat input, preheating temperature and et al[6]. Here we refer to the actual situation of the preheating work shown in Table 2 and determine preheating temperature necessary for the prevention of weld cracks for the following local preheating conditions:

i) Width of preheating.....An area of 10 cm on each side with the weld line as the center

ii) Measuring position of preheating temperature.....Plate surface 5 cm away horizontally from the weld line

iii) Continuous time of preheating.....Immediately before the commencement of welding

Among the preheating methods are gas preheating, preheating by electric heater and induction preachting. Preheating time required to each the prescribed preheating temperature varies according to the preheating methods employed, and the cooling process of the weld is affected to a great extent accordingly. **Fig. 6** shows actual instances of measurement of the temperature rise curve by preheating.

5. Selecting of Preheating Temperature for Preventing Weld Cracks

Fig. 2 shows the result of the process required to determine the local preheating temperature necessary for the prevention of cracks for given Pw-value.

You have only to seek Pw-value that satisfies $(t_c)_{cr} \leqq (t_c)_{ac}$ and local preheating temperatures. **Fig. 7** shows the relationship between the Pw-value and the local preheating temperature sought about the case of typical procedure conditions[6].

Explanation is now given about the procedure to establish control standard of the preheating temperatures with reference to the instances of HT80.

As mentioned in 4-3, the H-value for HT80 can be regarded as 1.6 cc/100g while K-value can be regarded as K=40h.

Suppose the P_{CM}-value of the plate thickness of

Table 4. Factors affecting on cooling time of weld.

Factor	Effect
Weld heat input Ambient temperature Weld run length Interpass temperature Preheating work { Preheating temperature / Time during preheating / Range of preheating	Larger these terms are, longer cooling time of weld becomes.
Plate thickness	Thinner the plate thichness is, longer cooling time of weld becomes.

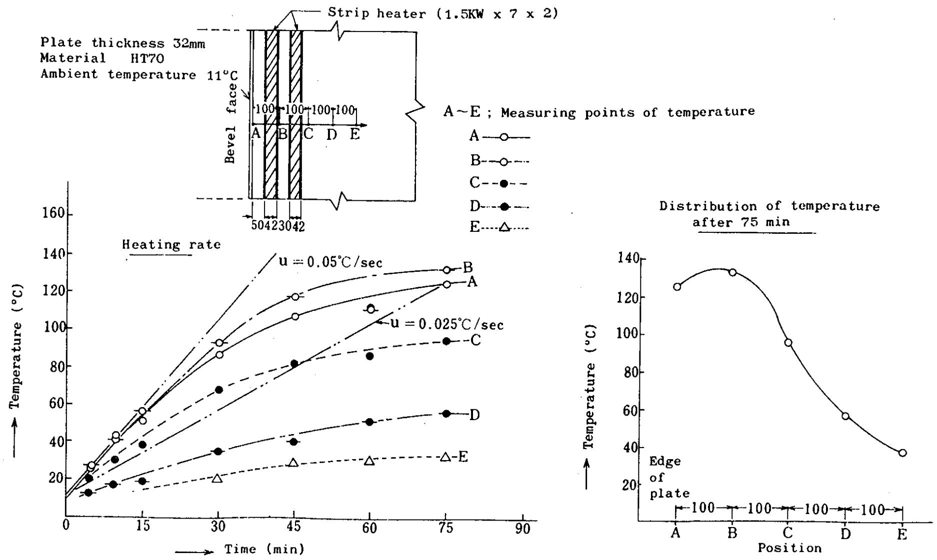
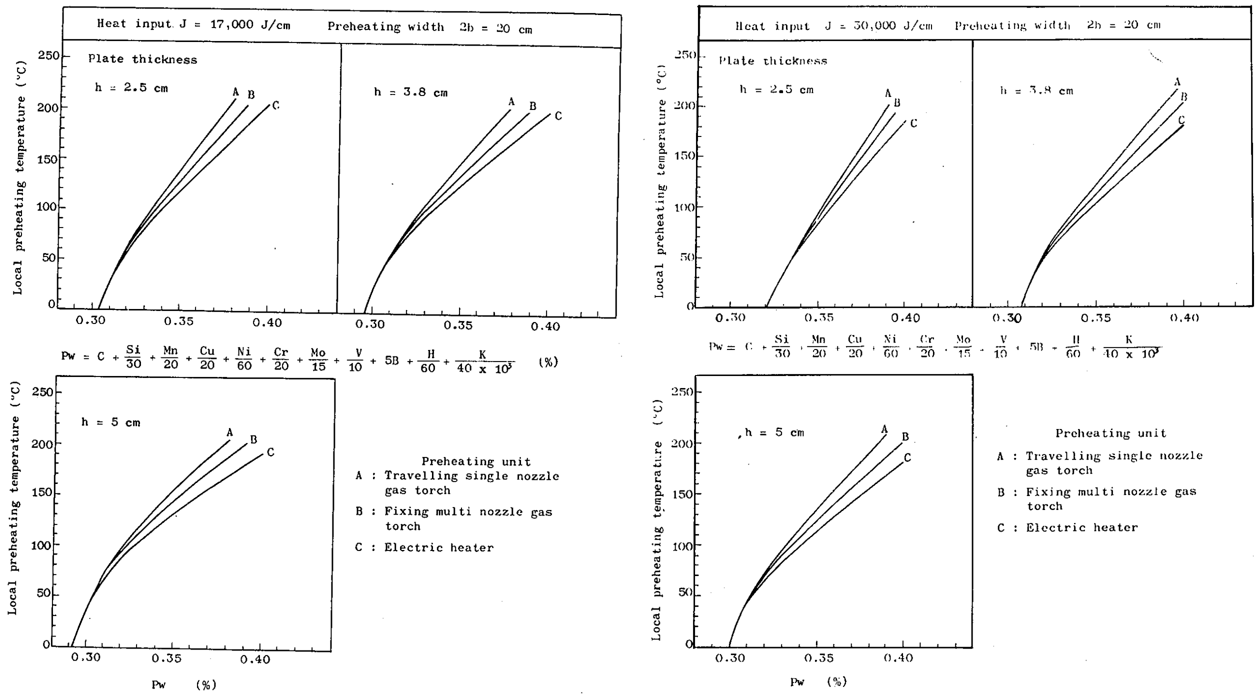


Fig. 6. Example of measurement of heating rate used electric heater.



(a) Weld heat input 17,000 J/cm, long weld run.

(b) Weld heat input 30,000 J/cm, long weld run.

Fig. 7. Relation of Pw-versus required preheating temperature.

HT80 is given in Fig. 4, $Pw = P_{CM} + \frac{H}{60} + \frac{K}{40000}$. So, Fig. 4 can be rewritten to indicate the relationship between the Pw value and plate thickness as in **Fig. 8.** When we read the preheating temperature necessary for the prevention of cracks from Fig. 7 for this Pw-value, it is possible for us to obtain the control standard of the preheating temperature of the plate thickness as shown in **Table 5.**

The foregoing indicates methods to select preheating temperatures assuming the P_{CM}-value, H-value and K-value to be certain values, but when the

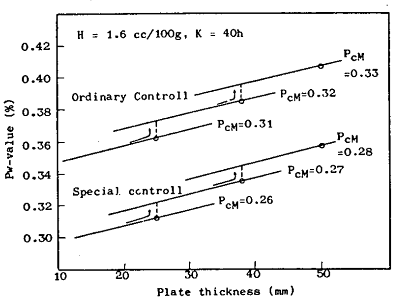


Fig. 8. Plate thickness versus Pw-value of HT80 for upper P_{CM}-value.

Table 5. One example of standards of preheating temperature for HT80.

Steel plates \ Plate thickness	t < 25	25 ≤ t < 38	38 ≤ t ≤ 50
Ordinarily commercial plates	165°C	180°C	200°C
Specially quality controlled plates	40°C	105°C	120°C

Weld heat input: 17000 J/cm   Heating unit: Electric heater

Table 6. Estimation of preheating temperature θ_L from θ_y.

Intensity of restraint \ Heat input	17,000 J/cm		30,000 J/cm	
K=70h	$\theta_y \leq 75$* $\theta_y \geq 125$	$\theta_L = \theta_y - 15$ $\theta_L = \theta_y + 50$	$\theta_y \leq 50$ $\theta_y \geq 125$	$\theta_L = 0$ $\theta_L = \theta_y + 30$
K=40h	$\theta_y \leq 75$ $\theta_y \geq 125$	$\theta_L = 0$ ** $\theta_L = \theta_y + 10$	$\theta_y \leq 75$ $\theta_y \geq 125$	$\theta_L = 0$ $\theta_L = \theta_y - 10$
K=10h	$\theta_y \leq 75$ $\theta_y \geq 125$	$\theta_L =$ $\theta_L = \theta_y - 30$	$\theta_y \leq 100$ $\theta_y \geq 125$	$\theta_L = 0$ $\theta_L = \theta_y - 60$

* For intermidiate θ_y, θ_L can estimate proprtionally.
** $\theta_y = 0$ means that preheating is unnecessary.

preheating temperature to avoid cracking is known in y groove restraint cracking test, it is possible to seek preheating temperatures θ to prevent cracks in steel structures concretely from **Table 6**[7].

6. Precautions

6-1 Precautions for Determining Preheating Temperature

a) Preheating methods

Heat an area 10 cm each on one side with the weld line in the center with gas or electric heater. Recommended as preheating method is a heat source that provides heat uniformly, if possible, over the entire area to be heated instead of a concentrated heat source like a gas torch.

b) Effect of ambient temperature

The preheating temperature to aboid weld crack shown in this report was sought for the sake of safety as RT=0°C. When the ambient temperature gets to the tune of RT=25°C, for instance, it is all right to take the preheating temperature about 10 percent lower than the case of RT=0°C[6].

c) Tack welds

In the case of tack welds, it is necessary to raise the local preheating temperature about 40°C or so in order to make the cooling time same with the case of regular welding (when the welding length is sufficiently long.)

If viewed from the point of the intensity of restraint, larger restraint is bound to occur than the case where the weld length is long because the weld length is short. As tack welds are likely to fail due to distortion as a result of preheating of regular heating and the thermal stress by welding, more emphasis should be laid on the preheating of weld tacks than on regular welding and it is necessary to make the preheating temperature higher than in regular welding.

d) Effect of wind

In the cooling time up to 100°C, heat radiation from the plate surface cannot be ignored. In the open air construction, the heat radiation is much rager than in a laboratory due to the effect of winds, the cooling time up to 100°C is likely to become shorter if under the same preheating condition it is also necessary to raise the preheating temperature depending on conditions.

e) No. of sheets of materials

The preheating temperature sought in 5 above relates to a case where two plates are put together to be welded. When three or four plates are made to cross like tee joints or cruciform joints, it is necessary to preheat each plate within the prescribed range (10 cm each on one side) and evaluate the welding heat input to be 2/3 or 1/2 as compared with the case where two plates are put together.

6-2 Precautions against Thermal Stress and Deformation by Preheating.

In some preheating methods, high restraint stress is made to occur in the welded part by the heat expansion of preheat thereby to trigger cracks[8]. To prevent this, it is necessary to expand the preheating area to include the material to be restrained without limiting to the welded parts alone and preheat carefully not to shorten the root gap as much as possible due to deformation by expansion through preheating.

It is also necessary to care exercise for the range of preheating and position since materials get deformed by the deformation by thermal expansion due to preheating, allowing a large force to occur to the tack welds and thus cause cracks.

Table 7. Comparison of preheating temperature for ordinary preheating and continuous preheating (HT80).

Preheating method	Steel plates	Plate thickness		
		t < 25	25 ≤ t < 38	38 ≤ t ≤ 50
Preheating only before welding	Ordinarily commercial plates	165°C	180°C	200°C
	Specially quality controlled plates	40°C	105°C	120°C
Continuous preheating	Ordinarily commercial plates	75°C	85°C	90°C
	Specially quality controlled plates	25°C	75°C	85°C

Weld heat input: 17000 J/cm, Heating unit: Electric heater

7. Selection of Preheating Temperature in Case of Continuous Preheating Kept Constant Temerature during Welding and Multipass Weld

7-1 Continuous Preheating Kept Constant Temperature during Welding

When preheating with an electric heater, for instance, it happens that preheating continues during welding and cooling. In such a case it is possible to lower the preheating temperature much below the level shown in Fig. 7 (Preneating takes place only before welding.) **Fig. 9** shows comparison of the necessary preheating temperature for Pw-value in a case where the preheating temperature is maintained constant during welding and cooling and a case where preheating takes place only before welding. For HT80 of which P_{CM}-values given in Fig. 4, necessary preheating temperatures against both preheating method are compared in **Table 7.**

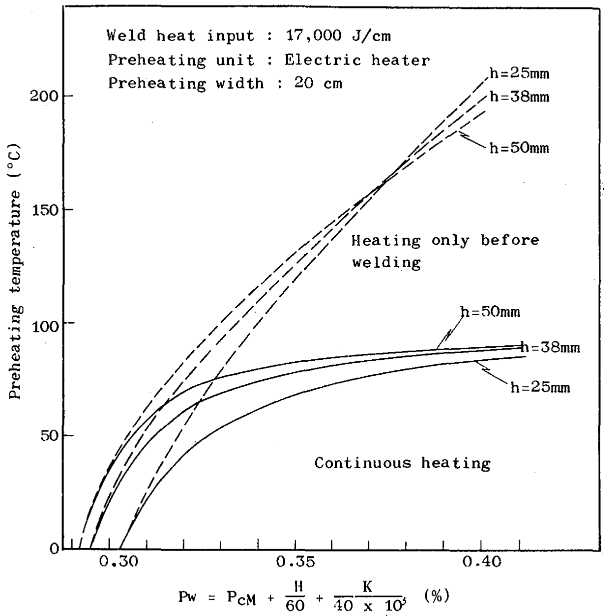


Fig. 9. Relation between Pw-value and preheating temperature in case of continuous heating.

7-2 Multipass Weld

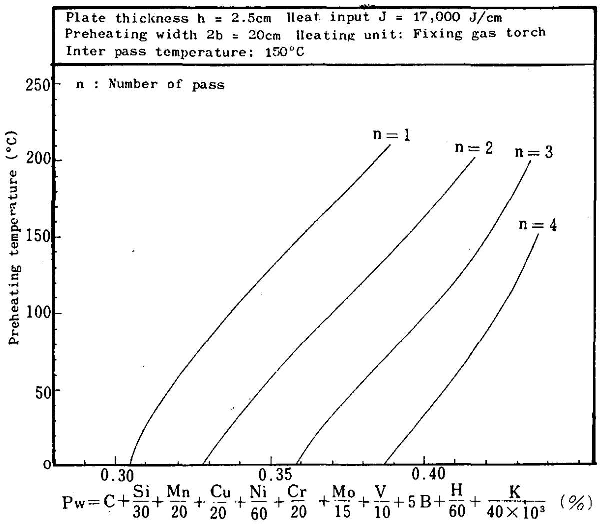


Fig. 10. Preheating temperature for multi pass weld.

In continuous multipass weld, generally if the interpass temperature is taken high, it is possible to prolong the cooling time after completion of welding till low temperature by the superimposition of welding heat. In this case, it is important to make sure that cracks will not occur until the next pass takes place. To this end, it is necessary to take comparatively high interpass temperature, but it is possible to lower the preheating temperature considerably in a method which is effective to joint of short weld run length. (See **Fig. 10**)

8. Summary

The JSSC Weld Cracking Study Group studied the prevention of weld cracks that occur during welding of steel constructions, and attempted to put the Pw criteria into practical application by reflecting the existing conditions of actual welding procedures on it, and recommended a method to select reasonable preheating temperatures.

References

1) JSSC Weld Cracking Study Group Report: Study on Weld Crack of Steel Structures, JSSC, Vol. 6, No. 60 (1970), p.1～34. (in Japanese)

2) Y. Ito and K. Bessyo: A Prediction of Welding Procedure to Aboid Heat Affected Zone Cracking, IIW Doc. No. IX-631-69.

3) JSSC Weld Cracking Study Group Report: Guidance Report for Determination of Safe Preheating Conditions without Weld Cracks in Steel Structures, JSSC, Vol. 8, No. 80 (1972), p.22-50 (in Japanese).

4) H. Tamura, M. Inagaki and Y. Ito: Weld Cracking Susceptibility of High Strength Steels, IIW Doc. No. IX-738-71.

5) K. Satoh, Y. Ueda and H. Kihara: Recent Trend of Researches on Restraint Stresses and Strains for Weld Cracking, IIW Doc. No. IX-788-72, X-659-72.

6) K. Satoh, S. Matsui, Y. Ito, K. Bessyo, R. Sakurai and S. Takahara: Determination of Preheating Conditions to Aboid Weld Cracking in Steel Constructions, IIW Doc. No. IX-730-71.

7) K. Satoh, S. Matsui, Y. Ito and K. Bessyo: Materials, Restraints versus Welding Procedures to Aboid Weld Cracking in Steel Constructions, The First International Symposium of Japan Welding Society on the Precaution of Cracking in Welded Structures Based on Recent Theoretical and Practical Knowledge, Nov., 1971.

8) K. Satoh: Preheat and Restraint versus Weld Cracking in Steel Constructions, Trans. of Japan Welding Soc., Vol. 1 (1970), No. 1. p.43-50.