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# Static Tensile and Brittle Fracture Strengths of Soft Welded Joints†

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**Abstract**

*Static tensile and brittle fracture behaviors of the welded joints having weld metal whose strength is lower than it of base metal, or soft welded joints, are investigated. The strength of the welded joints having soft weld metal is much elevated from it of the soft weld metal itself. It is effective to use soft weld metal in a part of weld metal from the viewpoint of efficiency of strength. The "Soft Ratio" Sr of weld metal required to guarantee the standard strength and the elongation of welded joints are considered. When Sr* $(=\sigma_u^W/\sigma_u^B)\geqq 0.93$*, ultimate tensile strength and elongation of all kinds of soft welded joints become almost equal to those of base metal. The brittle fracture strength of welded joints is affected more considerably with fracture toughness than yield strength of weld metal. The soft welded joints whose fracture toughness is a little better than it of the ordinary weld metal guarantee the sufficiently brittle fracture strength.*

## 1. Introduction

In the welded joints, it becomes a common idea that the strength of weld metal is equal to or higher than it of base metal from the viewpoints of efficiency of welded joints. Otherwise, it is effective to use the weld metal whose strength is lower it of base metal in order to prevent the initiation of weld cracking.[1] If welded joints having lower grade weld metal have a larger strength than it required as the welded joints, it is one of the useful welding procedure to use the lower grade welding rod.

The investigations have been made by the static tensile test of model specimens including a soft interlayer whose strength is lower than it of base metals.[2)~5)] The test results have revealed that the tensile strength approaches it of the base metal for sufficiently small values of the relative thickness of the soft interlayer.

In the future, as the welded structures become larger size and it becomes a larger demand to use the more thick plates of high tensile strength steel, the requirement to use the lower grade welding rods from a viewpoint of welding procedure will be arised. In this report, the static tensile and brittle fracture behaviors of the welded joints having weld metal whose strength is lower it of base metal —so called "Soft Welded Joints"— are investigated.

## 2. Static tensile behaviors of soft welded joints

### 2.1 Experiment

The following three kinds (four Series) of welded joints in each of which the size and the position of soft weld metal were different as shown in **Table 1** were employed for experimental work.

1 ; All soft welded joint (Series Ⓘ): Welded joints in which all weld metal are soften metal.

2 ; Partial soft welded joint in which only weld metal in a root part is soften metal (Series Ⓘ, Ⓘ): From the viewpoints of prevention of root cracking in the welding of thick plates, lower grade electrodes are used only in a root part and ordinary grade electrodes are used in other parts of weld metal.

3 ; Partial soft welded joint in which only weld metal in a part of plate surface is soften metal (Series Ⓘ): In order to examine the possibility to use the lower grade electrodes in repair welding, this partial soft welded joints are made.

The details on experiments are found in another report.[5)]

### 2.2 Tensile strength of all soft welded joints

Let *Sr* denote the "Soft Ratio" defined by the following equation.

$$Sr=\sigma_u^W/\sigma_u^B$$

where $\sigma_u^W$ is the tensile strength of weld metal and $\sigma_u^B$ is it of base metal.

**Figure 1** shows the relationships between the tensile strength of all soft welded joints $(\sigma_u/\sigma_u^B)$ and the *Sr* -value. A line ③ in **Fig. 1** is the line whose inclination angle to abscissa is 45 degrees. What all experimental values of the tensile strength are above the line ③, shows that the tensile strength of soft

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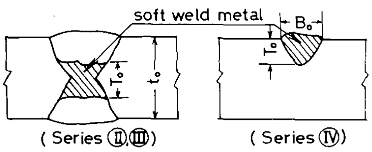
Table 1. Contents of experiments.

| Series | Welded joint | Contents of experiments |
|---|---|---|
| Ⅰ | All soft welded joint | (a) Effect of soft ratio (strength level of weld metal; HT80, HT60, HT50) |
| | | (b) Effect of specimen width ( typeL : $W_o$=500 mm typeM : $W_o$=$t_o$=70 mm ) |
| | | (c) Effect of groove shape ( X , U ) |
| Ⅱ | Root partial soft welded joint | (b) Effect of width(welding length) ($W_o$=3~92mm) |
| | | (d) Effect of thickness($T_o$) of soft weld metal (typeA : $T_o/t_o$≈1/2, typeB : $T_o/t_o$≈1/4 typeS : all soft welded joint, typeN: normal joint) |
| Ⅲ | Root partial soft welded joint | (a) Effect of soft ratio (strength level of weld metal ; HT80, HT60 , HT50 , MS ) |
| Ⅳ | Soft repair welded joint | (a) Effect of soft ratio (strength level of weld metal; HT80 , HT60 , HT50 , MS ) |
| | | (e) Effect of width($B_o$) of soft weld metal (type A; $B_o$≈20mm , type B: $B_o$≈10mm ) |



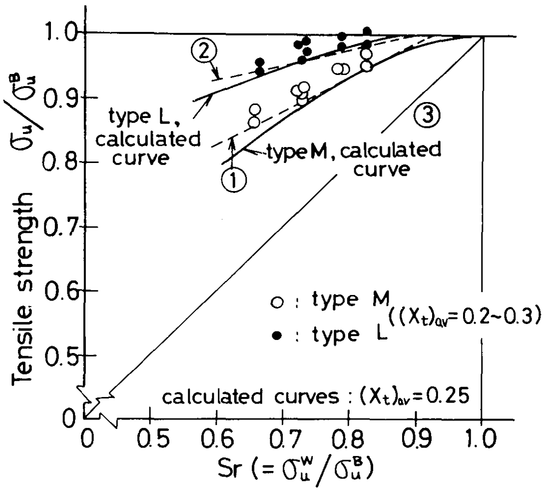




Fig. 1. Effect of soft ratio $Sr$ on tensile strength $\sigma_u/\sigma_u^B$ of all soft welded joints.

welded joints is larger than it of weld metal itself. As the soft ratio $Sr$ is closer to unity, $\sigma_u/\sigma_u^B$ approaches unity, that is, the strength of welded joints becomes nearly equal to strength of base metal.

The mark ○ in **Fig. 1** shows the results for a specimen having square cross-section (type M, $W_o=t_o=70$ mm) and the mark ● shows it for large width specimen (type M, $W_o=500$ mm). Compering the both, the strength of large width welded joints is larger than it of square section welded joints. As mentioned in the previous reports,[3), 5)] the strength for type L is almost the same as the one in a infinite wide plate.

In the previous reports[2)~5)] theoretical studies on tensile strength of welded joint including a soft interlayer were made. Using these results, ultimate tensile strength of soft welded joints can be calculated if dimensions of test specimen and soft weld metal is known. The solid curves in **Fig. 1** show the results calculated using authors' theoretical analysis for type L or type M, respectively. In **Fig. 1**, the experimental values agree well with the theoretical results. In this experiment, high tensile strength steel (HT 80) of 80 kg/mm$^2$ strength level was used as base metal. Considering the experimental results of the former fundamental study,[4)] this relationships between $\sigma_u/\sigma_u^B$ and $Sr$ in **Fig. 1** also hold true regardless of strength level of base metal.

### 2.3 Tensile strength of Partial soft welded joints

**Figure 2** shows the relationships between the

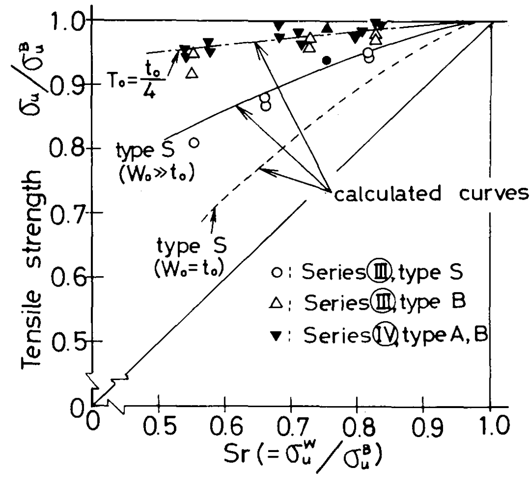



Fig. 2. Effect of soft ratio $Sr$ on tensile strength $\sigma_u/\sigma_u^B$ of partial soft welded joints.

tensile strength $\sigma_u / \sigma_u^B$ and the soft ratio $Sr$ obtained in the test Series Ⅲ -type S (○ -mark), -type B (△-mark) and Series Ⅳ -type A, B (▼-mark).

Tensile strength of partial soft welded joints is of cource larger than it of all soft welded joints. And as the size $T_o$ of soft weld metal becomes smaller, tensile strength of welded joints becomes larger.

The black symbols (▼-mark) in **Fig. 2** show the results for Series Ⅳ, or the welded specimens having soft weld metal in a part of plate surface. The experimental results in Series Ⅲ (type B) and Series Ⅳ, in both which the ratio of the thickness of soft weld metal $T_o$ to the plate thickness $t_o$ to is nearly equal to 1/4, are on one curve as shown **Fig. 2.** It is concluded that the tensile strength of partial soft welded joints having a certain constant value of $T_o / t_o$ is constant, regardless of the position of soft weld metal. The curves in **Fig. 2** show the results calculated using authors' theoretical analysis[2)~5)]. The experimental values agree well with the theoretical results in the same manner as **Fig. 1.**

### 2.4 Ductility of soft welded joints

In the soft welded joints, their strength is generally elevated from it of the soft weld metal itself, while their ductility becomes smaller than it of the soft weld metal or base metal.

When the ductility of tensile test specimens is represented by the elongation in percent in a certain gauge length $L_o$, it is affected significantly by the magnitude of the gauge length $L_o$. The elongation measured after fracture is the sum of local elongation and uniform elongation. In the percent elongation measured over the gauge length $L_o$, the term concerned with the uniform elongation is independent of the gauge length, while the term concerned with the local elongation depends upon $L_o$. As the percent elongation in tensile test specimens depends upon the gauge length $L_o$, it becomes a serious matter of great concern to choose the value of gauge length $L_o$ in the evaluation of the ductility of welded joints. If the ductility of welded joints is evaluated by the uniform elongation $\varepsilon_u$, the problem how long the gauge length should be chosen can be taken away.

**Figure 3** shows the relationships between uniform elongation $\varepsilon_u$ and soft ratio $Sr$ for various Series. As the $Sr$-value becomes smaller, uniform elongation $\varepsilon_u$ becomes smaller than it of base metals or normal welded joints whose weld metal has same strength level as its base metal. Uniform elongation $\varepsilon_u$ of partial soft welded joints is larger than it of all soft welded joints. If $Sr \geqq 0.8$ in partial soft welded joints and $Sr \geqq 0.9$ in all soft welded joints, uniform elongation of soft welded joints becomes neary equal to it

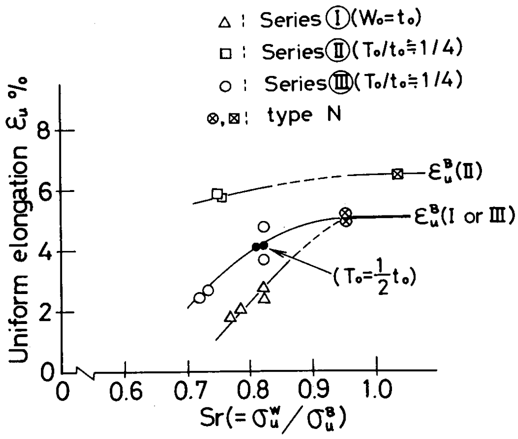



Fig. 3. Relation between uniform elongation $\varepsilon_u$ and soft ratio $Sr$.

of base metals.

### 2.5 Soft ratio required to guarantee the standard strength as welded joints

Mechanical properties such as tensile strength and ductility of welded joints must be different by the procedures of welding and the combinations between base metals and welding rods, because there is mechanical heterogeneity in welded joints. The values of mechanical properties required as welded joints must be dependent on the welding structures and the basic idea of design. In this paper, that basic idea of design does not be discussed in detail and the following two standards are considered as the required strength $\sigma_u$ of welded joints.

(Standard Ⅰ) $\sigma_u \geqq \sigma_u^B$ (strength of base metal)

(Standard Ⅱ) $\sigma_u \geqq$ (guaranteed strength for design)

Tensile strength $\sigma_u$ of soft welded joints can be calculated by analytical method as above mentined, but in a engineering sight, it is considered that relationships between tensile strength $\sigma_u$ and soft ratio $Sr$ are estimated by a straight lines connecting the lowest experimental values in each series as shown in **Figs. 4, 5.** These lines are summarized in **Fig. 6.**

In **Fig. 6,** the all lines from ① to ④ becomes $\sigma_u / \sigma_u^B = 1.0$ in $Sr = 0.9 \sim 0.93$. When $Sr(=\sigma_u^W / \sigma_u^B) \geqq 0.93$, ultimate tensile strength of all kinds of soft welded joints becomes almost equal to it of base metal.

The soft ratio $Sr^D$ required to guarantee the standard strength of base metal in standard (Ⅱ) is a function of $\sigma_u^B / \sigma_u^D$ because the tensile strength $\sigma_u^B$ of base metal is generally larger than the standard strength $\sigma_u^D$ of base metal. If it is considerd that the relationship between $\sigma_u / \sigma_u^B$ and $Sr$ in all soft welded joints is represented by the line ① in **Fig. 6** and it in partial soft welded joints is represented by the line ④ in **Fig. 6,** the $Sr^D$-values show as a function of $\sigma_u^B / \sigma_u^D$ as dotted curves ① or ② in **Fig. 7.**

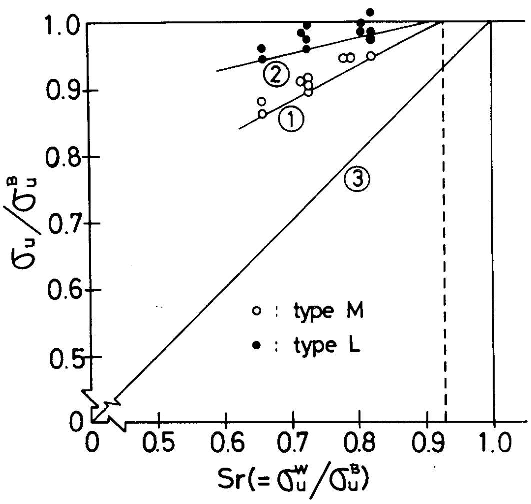



Fig. 4. Relation between $Sr$ and tensile strength. (all soft welded joints)

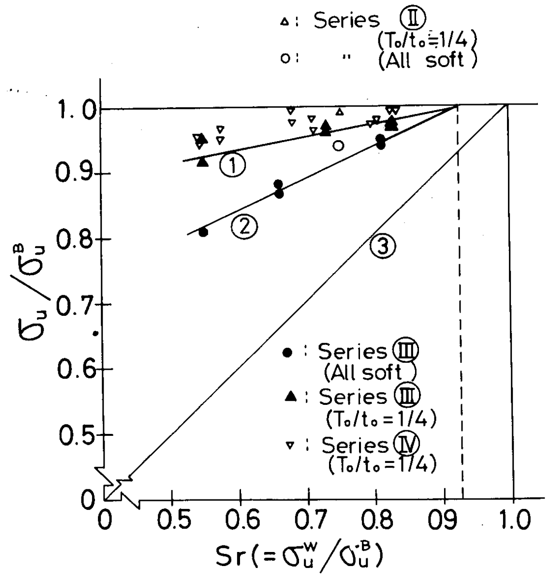



Fig. 5. Relation between $Sr$ and tensile strength. (Partial soft welded joints)

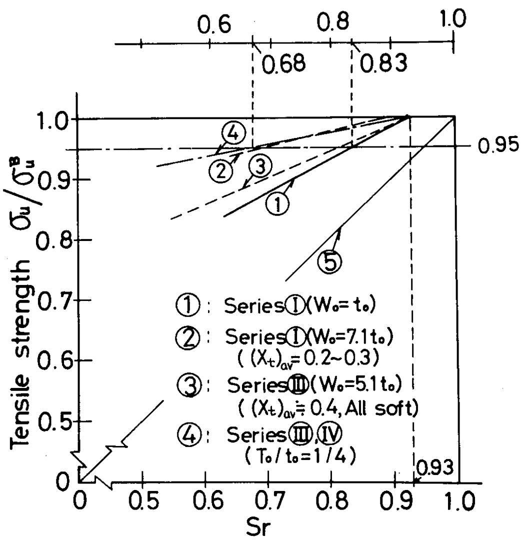



Fig. 6. Effect of $Sr$ on tensile strength (Series Ⅰ~Ⅳ).

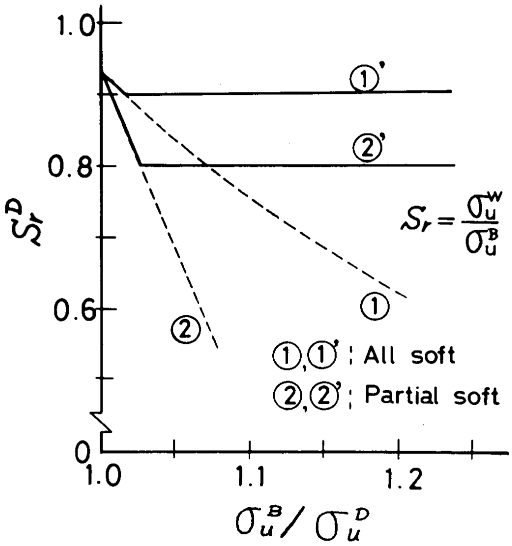



Fig. 7. Relation between $Sr^D$ and $\sigma_u^B / \sigma_u^D$ .

As mentioned above, when

$Sr < 0.9$ (in all soft welded joints)

$Sr < 0.8$ (in partial soft welded joints, $T_o/t_o=1/4$), the uniform elongation of soft welded joints becomes smaller than it of base metal. The soft ratio $Sr^D$ required to guarantee the standard strength $\sigma_u^D$ and the uniform elongation as same as it of base metal are given as the solid curves①',②'in **Fig. 7.**

## 3. Brittle fracture behaviors of soft welded joints

### 3.1 Experiment

Tensile tests of soft welded joints having notch in weld metal were carried out and the brittle fracture behaviors of soft welded joints are investigated.

Two plates of a high tensile strength steel (HT80) of 80 $kg/mm^2$ strength level were submerged welded with electrodes having 80, 60 and 50 $kg/mm^2$ strength level. The average thickness $(H_o)_{av}$ of weld metal is 13~14 mm. **Table 2** shows the chemical compositions, the mechanical properties at room temperature and results of V -notch Charpy test of the material.

**Figure 8 (a)** shows the size of deep notch test specimens and **Fig. 8 (b)** shows the shape and size of small scale bending COD specimen to estimate the critical COD $\Phi_c$ of base metal and weld metals.

The details on experiments are found in another report.[6)]

### 3.2 Experimental results

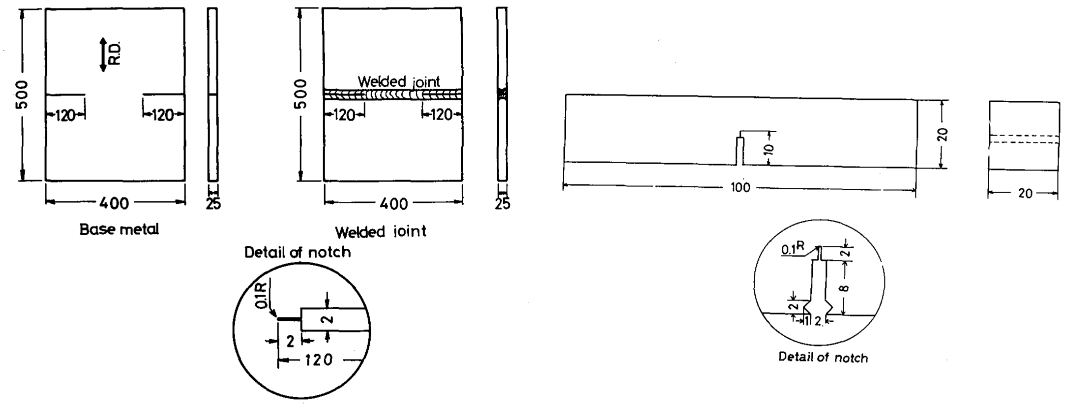
**Figure 9** shows the relationships between fracture net stress and temperature. The curves $\sigma_Y$(○), $\sigma_Y$(△) etc. in **Fig. 9** show the temperature dependence of the yield stress (0.2 % proof stress) of base metal (HT80) and weld metals.

The fracture stress-temperature curves of welded

Table 2. Chemical compositions and mechanical properties.

| Steel | Chemical composition (%) C | Si | Mn | P | S | Mo | Ni | Cr | V | Y. S. kg/mm² | T. S. kg/mm² | vTs °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B.M. | 0.14 | 0.23 | 0.90 | 0.012 | 0.008 | 0.44 | Tr. | 0.73 | 0.03 | 75.3 | 82.1 | -88 |
| W.M. (80) | 0.10 | 0.47 | 1.25 | 0.014 | 0.016 | 0.45 | 1.20 | 0.59 | 0.01 | 59.0 | 81.3 | -43 |
| W.M. (60) | 0.10 | 0.37 | 1.31 | 0.015 | 0.013 | 0.45 | 0.04 | 0.39 | 0.01 | 56.3 | 70.8 | -75 |
| W.M. (50) | 0.13 | 0.24 | 0.91 | 0.011 | 0.009 | 0.40 | 0.02 | 0.79 | 0.025 | 49.4 | 64.4 | -53 |

Tr. : Trace




(a) (b)

Fig. 8. Deep notch specimen and COD bending specimen.

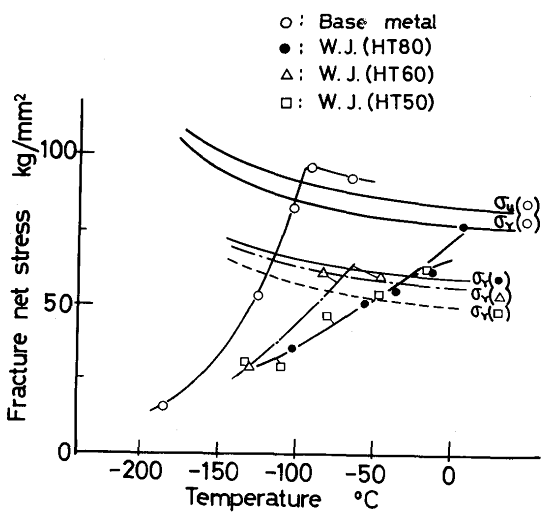



Fig. 9. Relation between fracture net stress $\sigma_f$ and test temperature.

joints shift to high temperature side in comparison with it of base metal (HT80). In this experiment, the welded joints using welding wires for HT60 have the largest strength in comparison with the other welded joints. There is little difference in the fracture strength between the welded joints having welding wires for HT80 and these for HT50. Comparing the size of the $_vT_S$ (°C) -values in these weld metal, weld metal for HT60 has the lowest value and it for HT50, for HT80 is in order. The fracture strength depends largely on the fracture toughness ($_vT_S$-value). Even if the strength of the weld metal is lower than it of base metal, the fracture strength of the welded joints using welding rods which have a higher toughness value becomes larger than it of base metal or welded joints using welding rods which have the same strength level as base metal.

**Figure 10** shows the relationships between the critical crack opening displacement $\Phi_c$ and the receprocal of testing temperature $1/T$(°K). The lines in

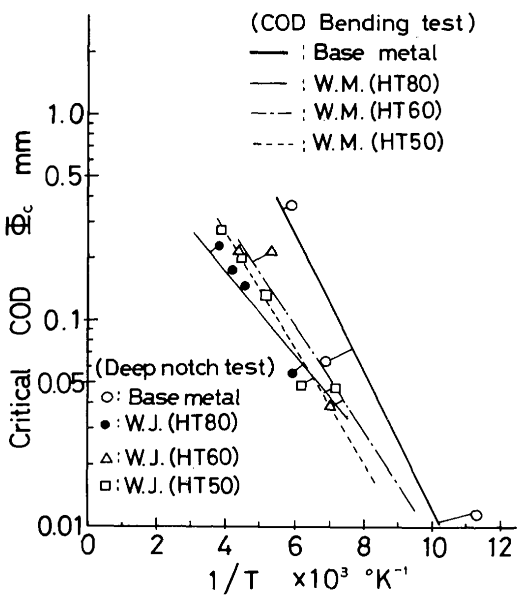



Fig. 10. Relation between critical COD $\Phi_c$ and $1/T$.

**Fig. 10** shows the $\Phi_c$ -$1/T$ relationships obtained by small scale bending COD testing and the experimental values plotting in **Fig. 10** are the $\Phi_c$-values obtained from Deep Notch Test. The both results agree very well. In $\Phi_c$ -value, also, it of welding rod for HT60 is largest value and it for HT50, for HT80 in order becomes smaller.

As mentioned in our another report,[6] the fracture behaviors of the soft welded joints are affected with the plastic constraint of the harder base metal. However, in this experimental range, it may be recognized the effect of this plastic constraint be neglected.

### 3.3 Brittle fracture initiation temperature $(T_{io})_{1/2}$ and soft ratio of weld metal

Denoting the brittle fracture initiation temperature at which the fracture stress $\sigma_f = 1/2\sigma_{YO}(\sigma_{YO}$: yield stress at sub-zero) by $(T_{io})_{1/2}$, the authors employ the $(T_{io})_{1/2}$ -value as the parameter representing the brittle fracture behaviors.

Let define the ratio of yield stress of weld metal $\sigma_{YO}^W$ to it of base metal $\sigma_{YO}^B$, or $\sigma_{YO}^W/\sigma_{YO}^B$ as Soft Ratio $(Sr)_Y$ of yield stress of weld metal. The temperature $(T_{io}^B)_{1/2}$ at which the fracture stress $\sigma_f$ of soft welded joints having a notch in weld metal becomes equal to $1/2\ \sigma_{YO}^B$ can be calculated equally well by $\Phi_c$ or $\rho_c^+$ criterion. In this paper, the basic concept employed expediently for discussion is that brittle fracture should initiate when tensile yield zone $\rho^+$ formed ahead of a pre-existing crack attaines a critical size $\rho_c^+$, because the authors adopt the experimental equations showed by Koshiga et. al.[7] as the relationship between fracture toughness $\rho_c^+$ and temperature and between $\rho_c^+$ and ${}_VT_S$-value. The relationship between $\rho_c^+$ -value and temperature was given by Koshiga et. al. as follows.

$$\rho_c^+ = \alpha(T/100)^5 \quad (\alpha \text{ in mm, } T \text{ in °K}) \tag{1}$$

where $\alpha$ is a material constant.

The tensile yield zone size $\rho^+$ in a infinite plate subjected to uniform tensile stress $\sigma$ is determined by

$$\frac{c}{a} = cos\left(\frac{\pi}{2}\frac{\sigma}{\sigma_Y}\right) \tag{2}$$

where

$a = c + \rho^+$

When $\sigma < 0.6\ \sigma_Y$ ($\sigma_Y$: yield stress), the relationship between $\rho^+$ and $\sigma$ is given approximately as follows.

$$\frac{\rho^+}{c} = \frac{\pi^2}{8}\left(\frac{\sigma}{\sigma_Y}\right)^2 \tag{3}$$

It is generally recognized that relation between yield stress $\sigma_Y$ and temperature $T$(°K) is given as follows

$$\sigma_Y = \sigma_{YO}\, exp\left\{ D\left(\frac{1}{T} - \frac{1}{273}\right)\right\} \tag{4}$$

where $D$ is a material constant.

Denoting the material constants of base metal by $\alpha^B$, $D^B$ and these of weld metal by $\alpha^W$, $D^W$, the $(T_{io}^B)_{1/2}$ -value at which $\sigma_f = 1/2\ \sigma_{YO}^B$ can be calculated by following equations for base metal and soft welded joints respectively.

$$\text{Base metal}: \frac{\alpha^B}{c}\left\{\frac{(T_{io}^B)_{1/2}}{100}\right\}^5 = \frac{\pi^2}{32}\ exp\left\{\frac{2D^B}{273} - \frac{2D^B}{(T_{io}^B)_{1/2}}\right\} \tag{5}$$

$$\text{Welded joints}: \frac{\alpha^W}{c}\left\{\frac{(T_{io}^B)_{1/2}}{100}\right\}^5 = \frac{\pi^2}{32}\frac{1}{(Sr)_Y^2} \times exp\left\{\frac{2D^W}{273} - \frac{2D^W}{(T_{io}^B)_{1/2}}\right\} \tag{6}$$

Let consider the relationship between $(Sr)_Y$-value and fracture toughness in the case which $(T_{io}^B)_{1/2}$ -value for soft welded joints becomes equal to $(T_{io}^B)_{1/2}$ -value of base metal. If the $(T_{io}^B)_{1/2}$ -value of welded joints is equal to it of base metal, from eqs. (5), (6),

$$\frac{\alpha^B}{\alpha^W} = (Sr)_Y^2\ exp\left\{2(D^W - D^B)\left(\frac{1}{(T_{io}^B)_{1/2}} - \frac{1}{273}\right)\right\} \tag{7}$$

The $(T_{io}^W)_{1/2}$ -value at which $\sigma_f = 1/2\ \sigma_{YO}^W$ is employed as the parameter representing the brittle fracture toughness of weld metal. $(T_{io}^W)_{1/2}$ is given as follows.

$$\frac{\alpha^W}{c}\left\{\frac{(T_{io}^W)_{1/2}}{100}\right\}^5 = \frac{\pi^2}{32}\ exp\left\{\frac{2D^W}{273} - \frac{2D^W}{(T_{io}^W)_{1/2}}\right\} \tag{8}$$

From eqs. (7), (8), the relationship between $(T_{io}^B)_{1/2}$ and $(T_{io}^W)_{1/2}$ is given as following equation.

$$(Sr)_Y = exp\left\{\frac{D^W}{(T_{io}^W)_{1/2}} - \frac{D^W}{(T_{io}^B)_{1/2}}\right\}\left\{\frac{(T_{io}^B)_{1/2}}{(T_{io}^W)_{1/2}}\right\}^{-5/2} \tag{9}$$

The relationship between $D$-value and $\sigma_{YO}$ is given approximately as following as shown in previous report.[8]

$$D = 325 - 65\ \ln\ \sigma_{YO} \tag{10}$$

So that

$$D^W = D^B - 65\ \ln\ (Sr)_Y \tag{11}$$

When the yield strength of base metal is determined the relationship between $(Sr)_Y$-value and $\Delta(T_{io})_{1/2}$ $(=(T_{io}^W)_{1/2}-(T_{io}^B)_{1/2})$ can be calculated from eq. (13).

**Figure 11** shows the relationship between $(Sr)_Y$ and $\Delta(T_{io})_{1/2}$ when the $(T_{io}^B)_{1/2}$-value of soft welded joints becomes equal to $(T_{io}^B)_{1/2}$-value of base metal, for example in $\sigma_{YO}^B=70$ kg/mm$^2$. As the $(Sr)_Y$- value becomes small, $-\Delta(T_{io})_{1/2}$-value becomes larger. For example when $(Sr)_Y=0.8$, if $-\Delta(T_{io})_{1/2}\approx 15\sim 20$°C, the fracture initiation temperature of soft welded joints becomes nearly equal to it of base metal.

In the foregoing considerations, we adopted the $(T_{io})_{1/2}$-value as the parameter which was a typical example of fracture toughness. It is very convenient that transition temperature obtained from the small scale testing, for example V-notch Charpy impact test, can be adopted as that parameter. It was shown by Koshiga et.al.[7] that the relatively good correlation between the fracture toughness $\rho_c^+$-value and the fracture transition temperature ${}_vT_S$ may exist. The relationship between the $\alpha$-value showed in eq.(1) and ${}_vT_S$-value is given as follows by Koshiga's report.[7]

$$\alpha=1.53\ exp\{-\frac{{}_vT_S\ (°C)}{40}\} \tag{12}$$

Denoting the fracture transition temperature of base metal and weld metal by ${}_vT_S^B$ and ${}_vT_S^W$ respectively, the relationship between $(Sr)_Y$ and $\Delta\,{}_vT_S\ (={}_vT_S^W-{}_vT_S^B)$ when the $(T_{io}^B)_{1/2}$-value of soft welded joints becomes equal to it of base metal can be obtained from eqs. (7), (8), (12) as following equation.

$$\Delta\,{}_vT_S={}_vT_S^W-{}_vT_S^B=80\{\ln(Sr)_Y\}\{1-65(\frac{1}{(T_{io}^B)_{1/2}}-\frac{1}{273})\} \tag{13}$$

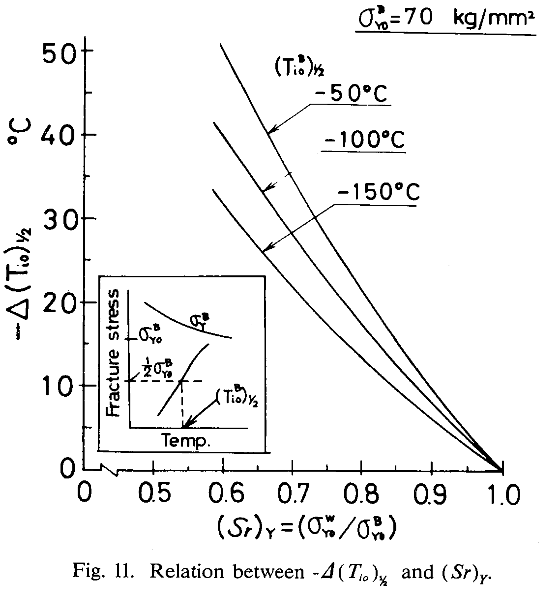



Fig. 11. Relation between $-\Delta(T_{io})_{1/2}$ and $(Sr)_Y$.

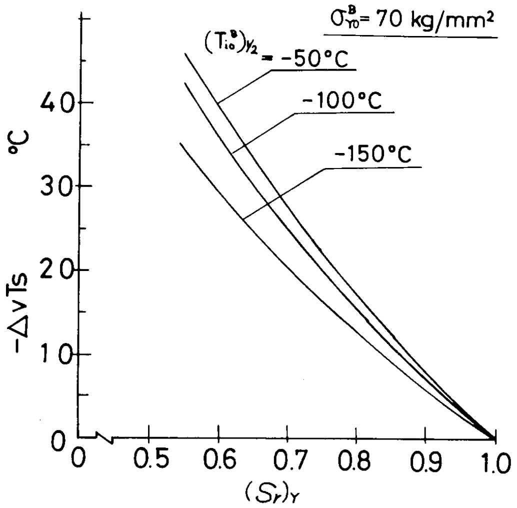



Fig. 12. Relation between $-\Delta\,{}_vT_S$ and $(Sr)_Y$.

**Figure 12** shows the relationship between $-\Delta\,{}_vT_S$ and $(Sr)_Y$ calculated from eq.(13). The results in **Fig. 12** showed results approximately similar to those in **Fig. 11.**

**Figure 13** shows the relationship between the $-\Delta\,{}_vT_S$ $(={}_vT_S^D-{}_vT_S^W)$ required to guarantee the design brittle fracture strength in the soft welded joints whose Soft Ratio is $Sr^D$, where the ${}_vT_S^D$-value is the ${}_vT_S$-value of weld metal required to guarantee the design strength when its strength level is equal to it of base metal. The $\Delta\,{}_vT_S$-value is affected with the strength of base metal and yield ratio of materials.

When $(Sr)_Y/Sr=1.0$,

(1) All soft welded joints; $|{}_vT_S|\gtrsim 8$°C $(\sigma_Y^W/\sigma_Y^B=0.9)$

(2) Partial soft welded joints; $|{}_vT_S|\gtrsim 17$°C $(\sigma_Y^W/\sigma_Y^B=0.8)$

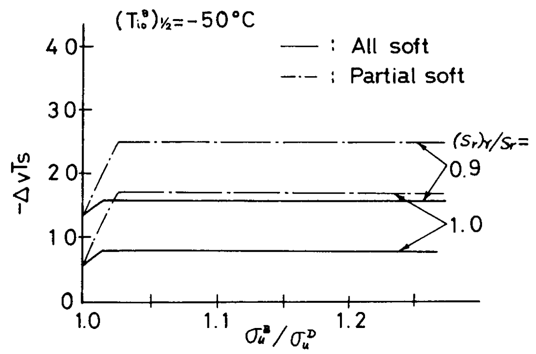



Fig. 13. Relation between $-\Delta\,{}_vT_S$ and $\sigma_u^B/\sigma_u^D$.

## 4. Conclusion

The results obtained in this report are summarized as follows:

(1) Static tensile strength and elongation in percent of soft welded joints are affected by the "Soft Ratio" $Sr\,(=\sigma_u^W/\sigma_u^B)$ of welded metal. The minimum

soft ratio $Sr^D$ required to guarantee the standard strength of base metal and ductility as same as these of base metal is determined from the results of this experiments (**Fig. 7**). Although the $Sr^D$-value is influenced by the tensile strength $\sigma_u^B$ of base metal and the size of soft weld metal, the $Sr^D$-values are given nearly as following equations.

In all soft welded joints; $Sr^D=0.9$

In partial soft welded joints; $Sr^D=0.8$

$(T_o = t_o/4)$

(2) The fracture toughness of weld metal required to guarantee the brittle fracture strength which is standard strength of design can be calculated when the soft ratio of weld metal is determined. The soft welded joints whose fracture toughness is a little better than it of the ordinary weld metal, guarantee the sufficiently brittle fracture strength (**Fig. 13**).

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