Toughness Improvement of the HAZ for Machine Structural Carbon and Low Alloy Steels (Report 2)†

— Effect of Cooling Time and Isothermal Heating Treatment on Medium and High Carbon Low Alloy Steels —

Fukuhisa MATSUDA*, Zhong Lin LI and Wu Shyuan LIU*****

Abstract

Succeeding to Report 1, medium and high carbon low alloy steels have been treated in this paper. The toughness of the simulated HAZ using Gleeble 1500 was investigated for commercial steels which contain 0.21 to 0.48 % C with 1.6N_i-0.5C_r-0.17M_o (SNCM) and 0.36 to 0.96% C with 1C_r-0.15M_o (SCM) or 1-1.5C_r (SC_r and SUJ2).

Main conclusions obtained are as follows:

(1) For Continuous Cooling Method an increase in Δt_C up to 300sec improved a little the ductility only in SNCM420 steel(C: 0.21%) but did not improve obviously for the other higher carbon steels.

(2) For Isothermal Heating Treatment at 473, 673 and 923K during weld heat cycle, ductilities were improved fairly for SNCM420 and SNCM439 and merely for SNCM447 at 673K, and merely for SCM435 and SC_r440 at 473 to 673K. However isothermal heating treatment at 923K is decreased the ductility for all steels, which is estimated due to tempered embrittlement.

KEY WORDS : (Toughness) (Fusion welding) (Heat-affected zone) (Medium, high carbon low alloy steels) (Cooling time) (Preheating)

1. Introduction

Medium and high carbon low alloy steels as SNCM(N_i-C_r-M_o), SCM(C_r-M_o) and SC_r and SUJ(C_r) are often used for transmission gear, gearcoupling, driving shaft and clutch drum and so on. These steels usually does not weld with fusion welding before, because there are two disadvantages of cracking and poor ductility in the weldments.

Recently by an advance of electron beam and laser beam welding methods welding of these steels is expected for construction of machine parts. Therefore, the investigation of weldability for these steels is required to make clear more.

The investigation of cold quenching cracking for these steels has been investigated[1], therefore the authors wish to investigate here the ductility as a part of toughness of weldment of these steels in relation to cooling condition during welding and isothermal treatment during welding, the details of which were shown in Report 1.

These steels in this paper are commercially used, which contain carbon from about 0.21 to 0.96%, and total alloy contents up to about 2.5%.

2. Steels Used and Experimental Procedures

2.1 Steels used

Medium and high carbon low alloy steel bars of JIS SNCM420, SNCM439, SNCM447, SCM435, SCM445, SC_r440 and SUJ2 were used as base metals SNCM steels have 1.6N_i-0.5C_r-0.17M_o with 0.21 to 0.48 % C, SCM have 1C_r-0.15M_o with 0.36 to 0.45 % C, SC_r 1C_r with 0.4% C and SUJ 1.5C_r with 0.96 % C. All of these are commercial steel bars whose chemical compositions and ductilities in Fig. 1 in Report 1 as received condition are given in **Table 1**.

2.2 Experimental procedures

The shape and size of the simulated round bar impact specimen is shown in Report 1 (see Fig. 1)

Simulted thermal cycle is given by a dynamic testing machine(Gleeble 1500) which is based on resistance heating.

In this investigation two kinds of thermal cycle were used. The first is Continuous Cooling Method(Fig. 2 in Report 1). Time for heating from room

† Received on November 6, 1989

* Professor
** Foreign Researcher
*** Graduate Student

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Table. 1 Chemical compositions and impact value of base metal of commercial medium and high carbon low alloy steels

Steels	Chemical Composition (wt. %)										Impact Value (J)*
	C	Si	Mn	P	S	Ni	Cr	Mo	N	O	
SNCM420	0.21	0.24	0.61	0.020	0.011	1.61	0.46	0.21			47.3
SNCM439	0.39	0.28	0.73	0.012	0.007	1.72	0.69	0.17	0.0094	0.003	62.1
SNCM447	0.48	0.26	0.81	0.025	0.012	1.65	0.72	0.15			28.5
SCM 435	0.36	0.23	0.80	0.022	0.013	0.10	1.11	0.15			—
SCM 445	0.45	0.24	0.78	0.017	0.018	0.07	1.07	0.15	0.0140	0.001	45.8
SC_r 440	0.40	0.29	0.76	0.025	0.012	0.07	1.09	0.02	0.0120	0.004	24.8
SUJ2	0.96	0.26	0.46	0.015	0.009	0.05	1.46	0.01	0.0073	0.001	—

* As received base metal. Size of specimen is same as in Report 1.

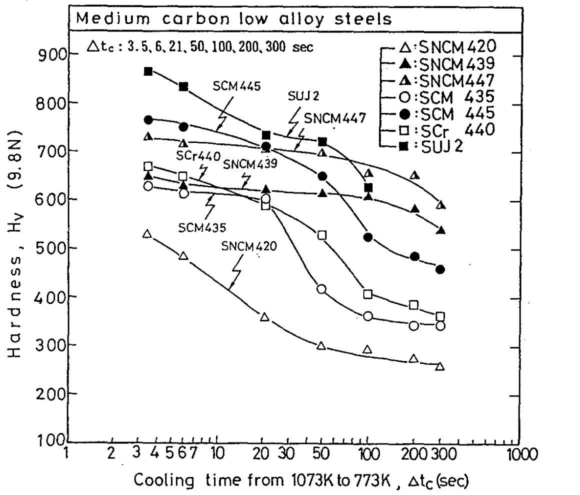
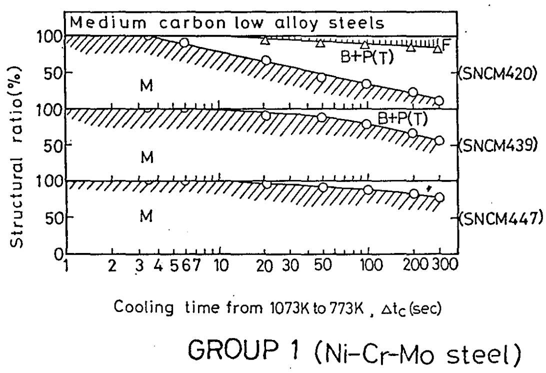
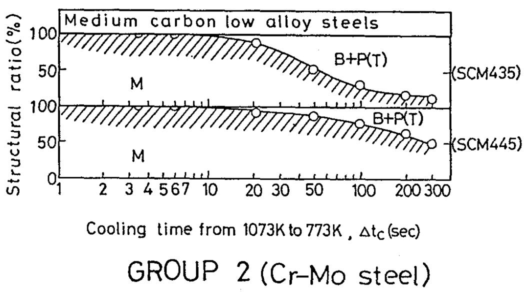


Fig. 1 Effect of cooling time on hardness of medium and high carbon low alloy steels

temperature(293K) to grain boundary liquation temperature (peak temperature T_P)[2] is 12sec, and for holding at the T_P is 6sec. T_P for SNCM420, SNCM439, SNCM447, SCM435, SCN445, SC_r440 and SUJ2 was given 1653, 1638, 1628, 1643, 1628, 1633 and 1548K. Then cooled to room temperature, on cooling time from 1073K to 773K ($\Delta t_{1073\text{-}773K}$: Δt_C) were changed to 7 levels of 3.5, 6, 21, 50, 100, 200 and 300sec.

The second thermal cycle is Isothermal Heating Treatment during weld heating cycle(Fig. 3 in Report 1). The heating cycle is same as the above-mentioned heating cycle. But on the cooling cycle, Δt_C is fixed as 3.5sec, and after cooled to each holding temperature(T_h : 473, 673 and 923K), the specimen was kept for 3 levels of holding time (t_h : 1000, 2000 and 3000sec) as an Isothermal Heating Treatment. Further, cooling to the





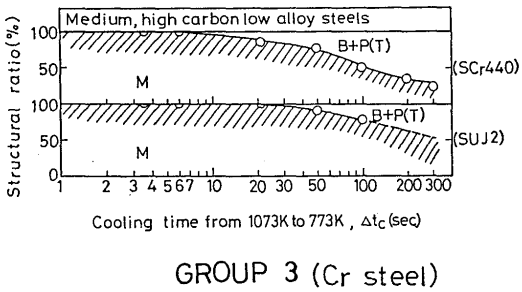


Fig. 2 Schematic illustration of relationship between cooling time and microstructure ratio of medium and high carbon low alloy steels

room temperature ($\fallingdotseq$ 293K) after the treatment was let by cooling rate of 275.5K/sec. The charpy test and the method of microstructural observation are same as section 2.2 in Report 1.

3. Experimental Results and Discussions

3.1 Continuous cooling method

Figure 1 shows the relationship between Δt_C(3.5, 6, 21, 50, 100, 200 and 300sec) and hardness for continuous cooling simulated HAZ for each steel used. Generally, increasing Δt_C shows a decrease in hardness in each steel, but in comparison with the result of simple carbon steels (see Fig. 4 in Report 1), the decreasing of hardness is not remarkable, especially in SNCM439 and 447 steels. Further, between Δt_C : 3.5 and 21sec, the hardness of these steels are all more than 600 H_V except SNCM420. Namely, as one of the authors pointed out in the previous paper[3], the susceptibilty of quenching cold cracking is enough high in the HAZ more than 600H_V. Therfore in order to avoid the cold cracking the hardness of the HAZ should be reduced generally less than 600H_V. Therefore the critical Δt_C over which the hardness is less than 600H_V is expressed as less than 3.5sec for SNCM420, about 20sec for SCM435 and SC_r440, 70sec for SCM445, 100sec for SNCM439 and SNCM447. Generally higher carbon content in the same kind of steel, longer the critical Δt_C. Further it is recognized that SNCM is longer in the critical Δt_C than SCM and SC_r in case of the same level of carbon content.

Figure 2 shows the relationship between Δt_C and the ratio of each microstructure in metallographic microscope in the simulated HAZ for each steel. Here M, F, and B+P(T) show martensite, ferrite and bainite and pearlite (including troostite) respectively. Here these steels are divided into three groups; N_i-C_r-M_o steels of SNCM420, SNCM439 and SNCM447 as group 1, C_r-M_o steels of SCM435 and SCM445 as group 2, and C_r steels of SC_r440 and SUJ2 as group 3 respectively. As a result, in each group, it is shown that martensite structure is easier to remain, when C content is increased and the formation of

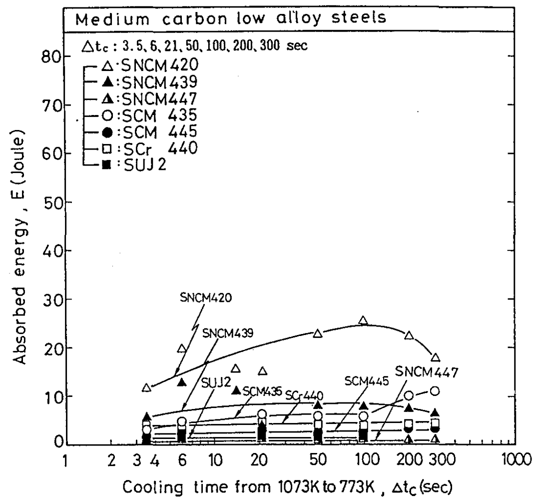


Fig. 3 Effect of various cooling time on absorbed energy

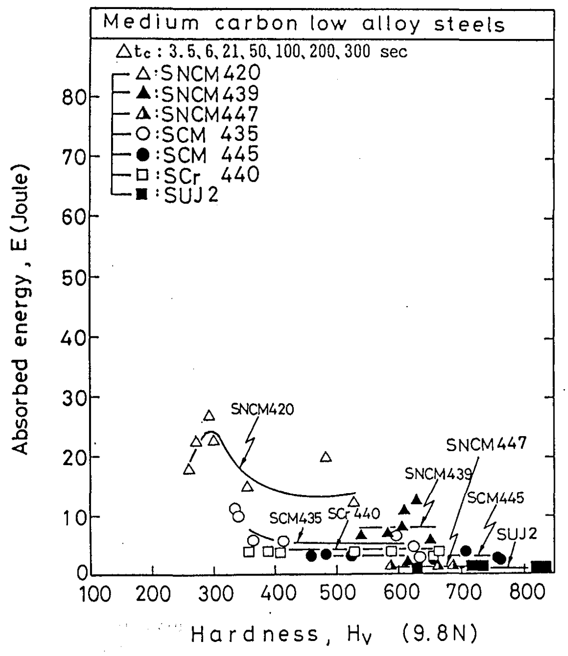


Fig. 4 Relationship between hardness and absorbed energy energy at various cooling time

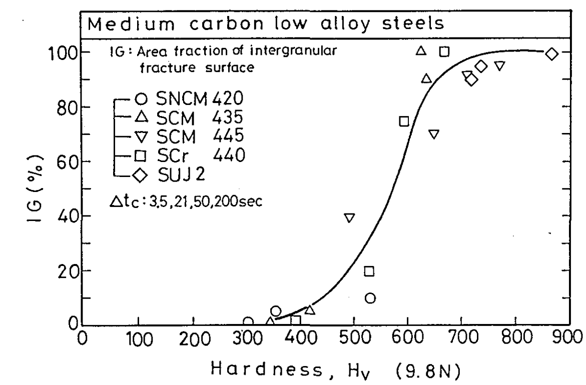
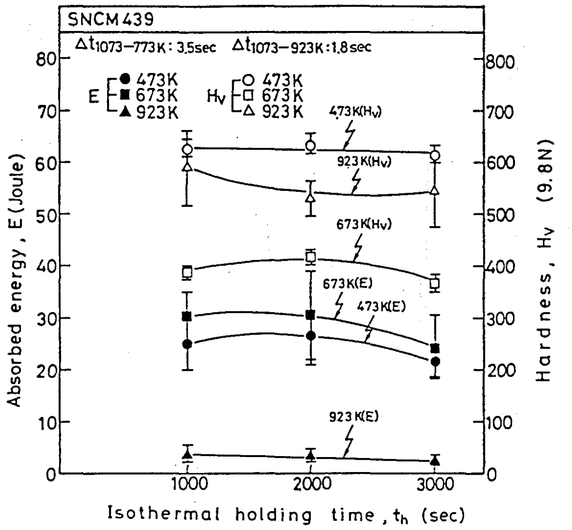
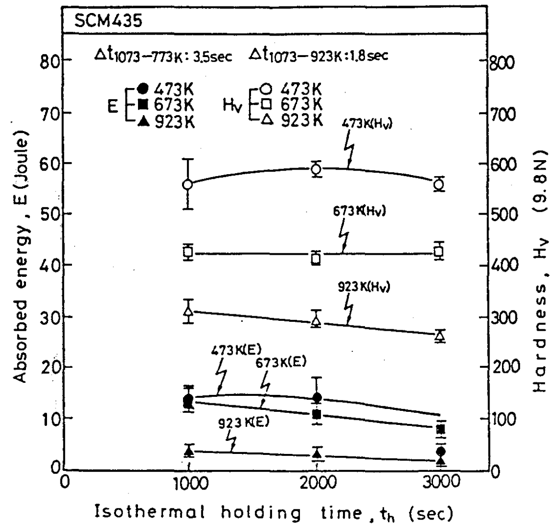


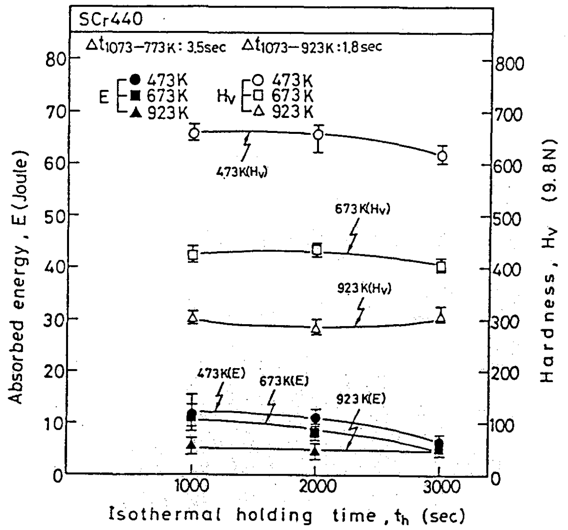
Fig. 5 Relationship between hardness and ratio of intergranular fracture surface at various cooling time



(a) SNCM439



(b) SCM435



(c) SC_r440

Fig. 6 Relationship between the absorbed energy and hardness and isothermal holding time for three different holding temperature

ferrite is not seen except SNCM420.

Furthermore, in each steel the ratio of the bainite structure was increased gradually with increasing Δt_C, however, in SUJ2, instead of formation of bainite, the pearlite structure was forming gradully with increasing Δt_C. There is a good relation judging from Fig.1 and Fig.2 between the ratio of martensite in microstructure and the hardness in the HAZ.

The relationships between Δt_C and absorbed energy for these steel is shown in **Fig. 3**. With increasing Δt_C the absorbed energy in SNCM420 is improved fairly up to 100sec, but is reduced again more than 200sec. However the other steels are not improved with increasing Δt_C. By means of initial preheating or increase in weld heat input in welding we usually expect to be improved the ductility as well as the crack susceptility in the HAZ. However, from the result of Fig. 3 it is considered that the improvement of the ductility of the HAZ is expected only for SNCM420 whose carbon content is 0.21%. However the improvement in SNCM420 is less than that in plain carbon steel in same level of carbon content.

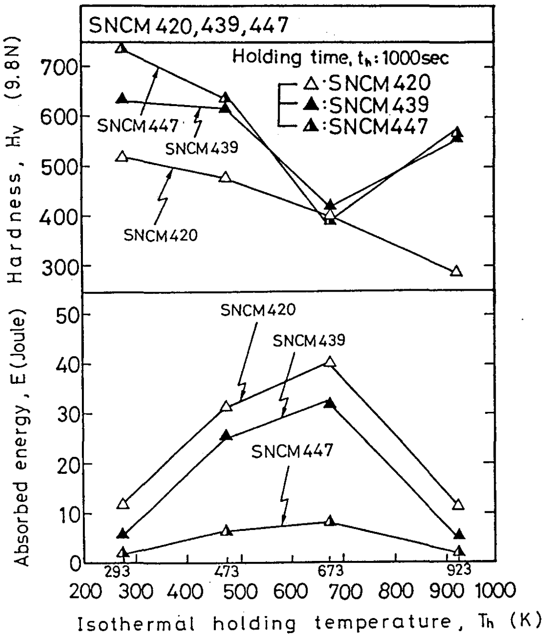
Figure 4 shows the ductility change against hardness of the HAZ. SNCM420 gradually decreases with hardness increase from 300 to $500H_V$, SCM435 is considered as the same tendency but the others are insensitive.

Figure 5 shows the relationship between the hardness and the ratio of intergranular fracture surface with various Δt_C as 3.5, 21, 50 and 200sec for these steels. As a result, intergranular fracture surface is abruptly increased when the hardness of the HAZ exceeds more than 400 to $500H_V$, and is reached to almost 100 % in case of hardness of $700H_V$ irrespective of type of steel.

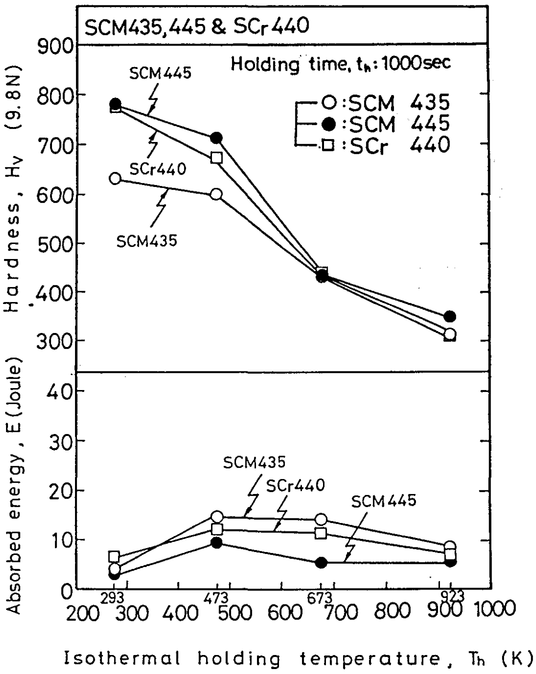
3.2 Isothermal heating treatment

On the continuous cooling of Δt_C : 3.5sec the specimen is stopped to cool at three different temperature as 473, 673 and 923K and held up to 3000sec. Accurate Δt_C is expressed as 1.8sec in case of 923K holding because temperature difference between 1073 and 923K is lesser. **Figure 6 (a)**, **(b)** and **(c)** show the relationship between the absorbed energy (E) and the hardness (H_V), and the isothermal holding time, t_h for three different temperature for SNCM439, SCM435 and SC_r440 steels. Holding time from 1000 to 3000sec does not obviously influence in the changes of the hardness and the absorbed energy although the decreasing in absorbed/energy is slightly observed.

However tendencies of improvement for the absorbed energy and softening of the hardness and different among



(a) SNCM420, 439 and 447



(b) SCM435, 445 and SC_r440

Fig. 7 Relationship between the absorbed energy and hardness and isothermal holding temperature on holding time, t_h: 1000sec

Fig. 6(a), (b) and (c). Therefore the authors have rearranged the results obtained by the isothermal heating treatment which are shown in **Fig. 7(a)** for SNCM and **Fig. 7(b)** for SCM and SC_r. Fig. 7 shows the relation between holding temperature and the absorbed energy and the hardness after 1000sec isothermal heating treatment. Moreover the data at Δt_C : 3.5sec in continuous cooling method are represented in 293K in the horizontal axis as a reference. Fig. 7(a) shows that holding temperature until 673K decreases the hardness and then improves the ductilities for all SNCM steels, although the improvement is fairly in SNCM420 and 439, but is merely in SNCM447. However holding temperature of 923K reversely decreases the ductility obviously, and increases again the hardness for SNCM439 and 447 although the hardness of SNCM420 is still reduced. These phenomena are considered as a tempered embrittlement of SNCM steels. As a result, isothermal heating treatment of SNCM steel should be limited to temperature until 673K. Fig. 7(b) shows that isothermal heating treatment of SCM and SC_r steels should be also limited to temperature between 473 and 673K because of tempered embrittlement, although improvement of the ductility of the HAZ is not enough for these steels.

In welding of low alloy steel with medium or high carbon content, we must pay attention for tempered embrittlement.

4. Conclusion

This paper has treated the variations of hardness, microstructure and ductility of the simulated HAZ for medium and high carbon (0.2 to 1.0 % C) low alloy steels which are designated as JIS SNCM, SCM and SC_r(including SUJ). Two different experiments were done using Gleeble 1500, one is continuous cooling method to room temperature, cooling time of Δt_C between 1073 to 773K of which are changed from 3.5 to 300sec, and the other is isothermal heating treatment at 473, 673 and 923K during continuous cooling in Δt_C : 3.5sec.

Main conclusions obtained are as follows;

(1) In continuous cooling method, the hardness of the HAZ, decreases with the increase of Δt_C for each steel depending on carbon content. In SNCM439 (0.39% C) and SNCM447 (0.48 % C) the decreasing in hardness is not remarkable with the increasing of Δt_C.

(2) Increasing carbon content in each same kind of steel prolongs the formation of martensite and decreases bainite in microstructure. Ferrite is formed only in SNCM420 and is increasing of Δt_C.

(3) Concerning the improvement of absorbed energy with Δt_C, there are a fair in SNCM420 up to 100sec of Δt_C and scarce in the other steels. As a result, the improvement of the ductility in the HAZ is generally difficult with an increase in Δt_C for these steels except SNCM420 whose C content is low as 0.21%.

(4) The absorbed energy of these steels is not represented by a simple relation with the hardness of the HAZ.
Intergranular fracture surface mode is abruptly increased while the hardness of the HAZ exceeded more than $600H_V$.

(5) In isothermal heating treatment, holding at the temperature up to 673K shows a fair improvement for SNCM420 and SNCM439, but a mere for the other steels. However an increase in holding temperature to 923K obviously decreases the ductility of the HAZ for all steels used, which is considered to be caused by tempered embrittlement. Holding time from 1000 to 3000sec scarecely influences the ductility and hardness of the HAZ.

References

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3) F. Matsuda et al. : Trans. JWRI, **15**-2 (1986), 135-141