MY 23 00334

PPA/T/72

EFFECT OF HEAT TREATMENT ON CARBON STEEL PIPE WELD~~MENT~~s

UNIT TENAGA NUKLEAR, JABATAN PERDANA MENTERI.

NUCLEAR ENERGY UNIT, PRIME MINISTER'S DEPARTMENT.

MALAYSIA

EFFECT OF HEAT TREATMENT ON CARBON STEEL PIPE WELDS

(Mohd b. Harun)

Abstract

The heat treatment to improve the altered properties of carbon steel pipe welds is described. Pipe critical components in oil, gasification and nuclear reactor plants require adequate room temperature toughness and high strength at both room and moderately elevated temperatures. Microstructure and microhardness across the welds were changed markedly by the welding process and heat treatment. The presentation of hardness fluctuation in the welds can produce premature failure. A number of heat treatments are suggested to improve the properties of the welds.

EFFECT OF HEAT TREATMENT ON CARBON STEEL PIPE WELDS

1. Introduction.

Carbon steel pipe is required to provide good weldability, including higher toughness in welds and resistance to cold cracking, and resistance to stress corrosion cracking in sour gas atmospheres. These tendencies not only enhance the utilization of the fundamental metallurgical knowledge on a wider scale, but also encourage the development of new processes to satisfy these requirements. It is well recognized that the excellent combination of strength and toughness is easily obtained by means of quenching and tempering of steel(1, 2). This fact means that the higher grade pipes with the lower carbon equivalent steels can be manufactured without any difficulties by the quenching and tempering process.

The most important advantage of the quenching and tempering process after pipe welding is drastic improvement in the mechanical properties of seam welds by the heat treatment. Plastic deformation prior to the heat treatment and a more uniform distribution of carbides in the prior microstructures possibly improve the quenching microstructures and sebsequently the toughness of rapidly heat-treated steels. Hardness distribution profile can be used to determine the strength and toughness of welding by the heat treatment.

It is well known that the mechanical properties of quenched and and tempered low carbon low-alloy steels are optimized by the refinement of prior autenitic grain size, lowering the transformation temperature to get lower bainite, martensile, or by mixed structure of both, providing fine and uniform substructures with high dislocation density as well as fine and uniform distribution of carbide precipitates(3).

In the present work, the examination of the effect on hardness and microstructure as the result of heat treatment will be carried out. It the welding hardness is greater, the weld will be susceptible to brittle failure. For example, the susceptibility of HSLA steel to hydrogen embrittlement depends strongly on the steel's hardness(4). Brittleness can promote failure at welding defects, such as microcracks and inclusion that act as nucleation sites.

2. Experimental procedures.

The material used in this study was carbon steel, the chemical composition of which is given in table 1. The material has been readily welded and used in a petroleum industry plant. The welded pipe has been cut to several pieces for heat treatment, microhardness measurement and metallography works. The specimens have been classed into three categories. Specimen A was an untreated or as-welded specimen. Specimen B was solution-treated at 900°C to 1 h, air-cooled and then retreated at 900°C for 1 h and water quenched. Specimen C was solution-treated at 900°C for 1 h and then air cooled. They were given a tempering and quenching at a temperature of 600°C for durations ranging from 2 h up to 100 h. The heat treatment was carried out in normal air atmosphere.

The hardness measurement was done by using a Vickers Microhardness tester at 100g load along weld metal (WM), heat affected zone (HAZ) and base metal (BM) to investigate the level of toughness in the welds. The microstructure was observed using an optical microscope and a scanning electron microscope (SEM).

Table 1 : Chemical composition of carbon steel used, wt.%

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	V	As	Ti	W	Fe
%	0.27	0.25	0.76	0.03	0.01	Trace	0.02	0.1	0.01	0.01	0.02	0.01	Trace	Balance

Table 2 : Chemical composition of the welding zones

Area \ Element	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	V	As	Ti	W
Base metal	0.27	0.25	0.76	0.03	0.01	Trace	0.02	0.1	0.01	0.01	0.02	0.01	Trac
Weld zone	0.08	0.83	1.26	0.02	0.01	-	0.03	0.1	0.12	0.02	0.02	0.01	-
HAZ	0.25	0.30	0.78	0.03	0.01	-	0.03	0.1	0.02	0.02	0.02	0.01	-

3. Result and discussion.

(i) Microstructure.

Microstructure of Weld sone for specimen A is shown in figure (1a) and (3a). The weld microstructure displayed columnar growth, fine grain size and Widmanstatten pattern as the weld metal underwent the autenitic-to-ferrite transformation. The Widmanstatten structure showed that the ferrite was present to a large extent as needle-like particles. In the HAZ, the microstructure showed the development of pearlite and very fine ferrite grains due to recrystallization (fig. 3b, left). In the base metal (BM), the dark patches of pearlite grains arrange themselves in bands with similar bands of ferrite grains on either side, their lamellar structure being unresolved under magnification. The banded condition may be developed during hot application of the ingot to a finished section and by arranging themselves in a rolling direction as shown in figure 3c, (left).

When the weld metal was heat-treated as in B and C, some areas of retained austenite at the ferrite grain boundaries are believed to undergo transformation to ferrite as shown in figures 1b and 1c, respectively. There was no significant change of microstructure in the base metal for specimen A after heat treatment at 600°C for 97 h and water quenching. For specimen B, the heat treatment at 600°C for 97 h and water quenching caused formation of smaller ferrite grain size, as shown in figures (3) and (4). This was caused by the process of recrystallization. It is evident that the microstructure of the heat-affected zone (HAZ) after heat treatment is similar to that of base metal because the unfavorable coarse-grained microstructure in as-welded HAZ is completely eliminated. However, the microstructure of welded metals is strongly affected by its chemical composition (see table 2) which is usually different from base metal and with its as-welded microstructure which is quite different from HAZ.

Using scanning electron microscope, microstructure changes as the result of welding have been investigated. The ferrite matrix can be observed clearly under magnification of x5000 as shown in figures 5 and 6. In the HAZ, heat transferred to the base metal caused transformation of ferrite and pearlite structures to small and chunky carbides as shown in figure 5(i). They were distributed in the matrix of ferrite. As the result of heat treatment for sample B at 600°C, 97 h and WQ, the carbide became smaller and approximately spherical as shown in figure 5(iii). The carbides also precipitated adjacent to the grain boundaries.

(ii) Microhardness measurement.

Figure 7 shows the significant hardness change across the weld, HAZ and base metal. The variation of microhardness with distance for as-received (A), heat-treated at 900°C for 1 h (AC) is shown in figure 7(i). There were hardness fluctuations along the weld zone, HAZ and base metal. After tempering at 600°C for 6 hours and water quenching as shown in figure 7(ii), the hardness fluctuations were removed to a relatively constant hardness value.

The hardness became more constant along the regions of WM, HAZ and BM after tempering at longer durations due to a more uniform distribution of carbide either in the matrix of ferrite or the grain boundaries. This is shown in figure 7(iii). This was confirmed by the microstructures in the WM, HAZ and BM which was about similar as shown in figure 4. The formation of the small and approximately spherodite carbide particles improved the hardness properties.

The hardness as a function of tempering time in the HAZ (adjacent to the weld zone) is shown in figure 8. The hardness value of sample A was higher compared with that of sample B. The hardness for both samples was increased rapidly at an early stage of the tempering time until about 10 hours. The hardness was maintained at constant value after further tempering times.

Fig. 1(a) : Weld microstructure in as-received carbon steel pipe. X200.

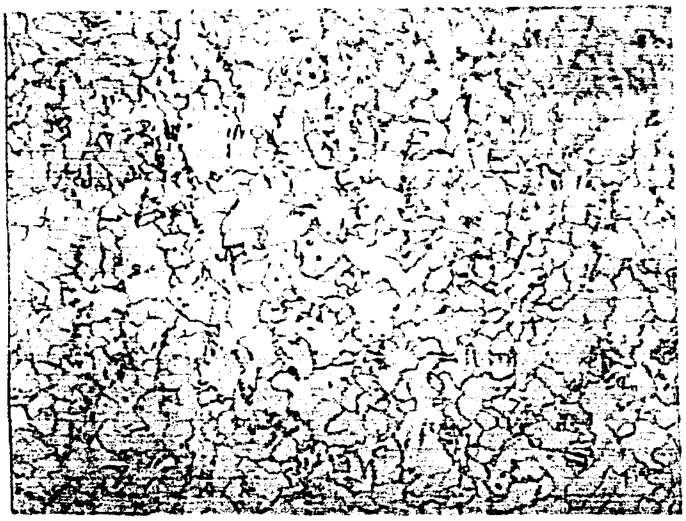


Fig. 1b : Weld microstructure in the same sample after heat treatment, 900°C, 1hr, AC.

Fig. 1c : Weld microstructure in the sample after heat treatment, 900°C, 1hr, AC and 900°C, 1hr, WQ.

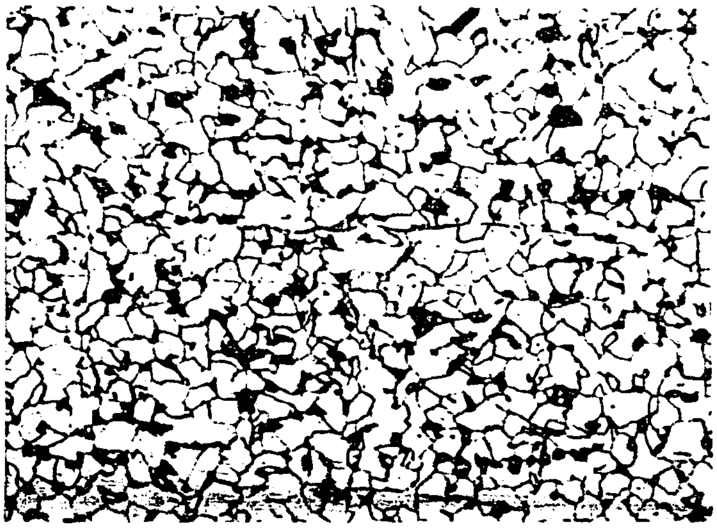


Figure 1(d) : Microstructure of carbon steel (base metal zone) after heat-treated at 900°C, (1), AC and 900°C (1), WQ showing grains of pearlite and ferrite X320.

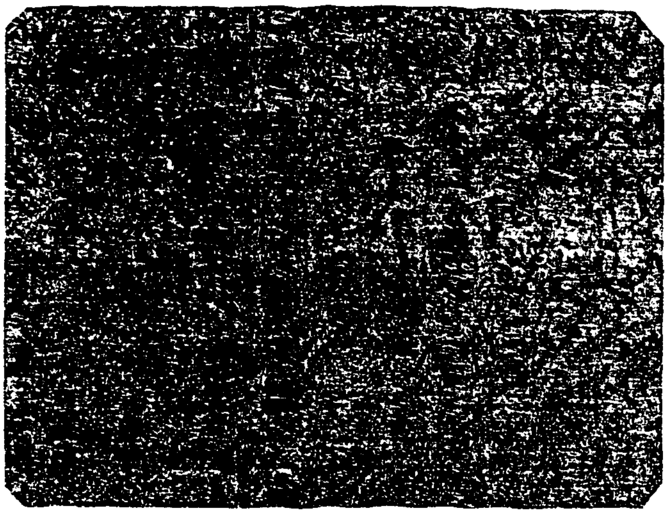


Fig. 2(a) : Microstructure of heat-affected zone in as-received sample X320.

Fig. 2b : Microstructure of heat-affected zone of the above sample after heat treatment(900°C, 1hr, AC and 900°C, 1hr, WQ). X320.

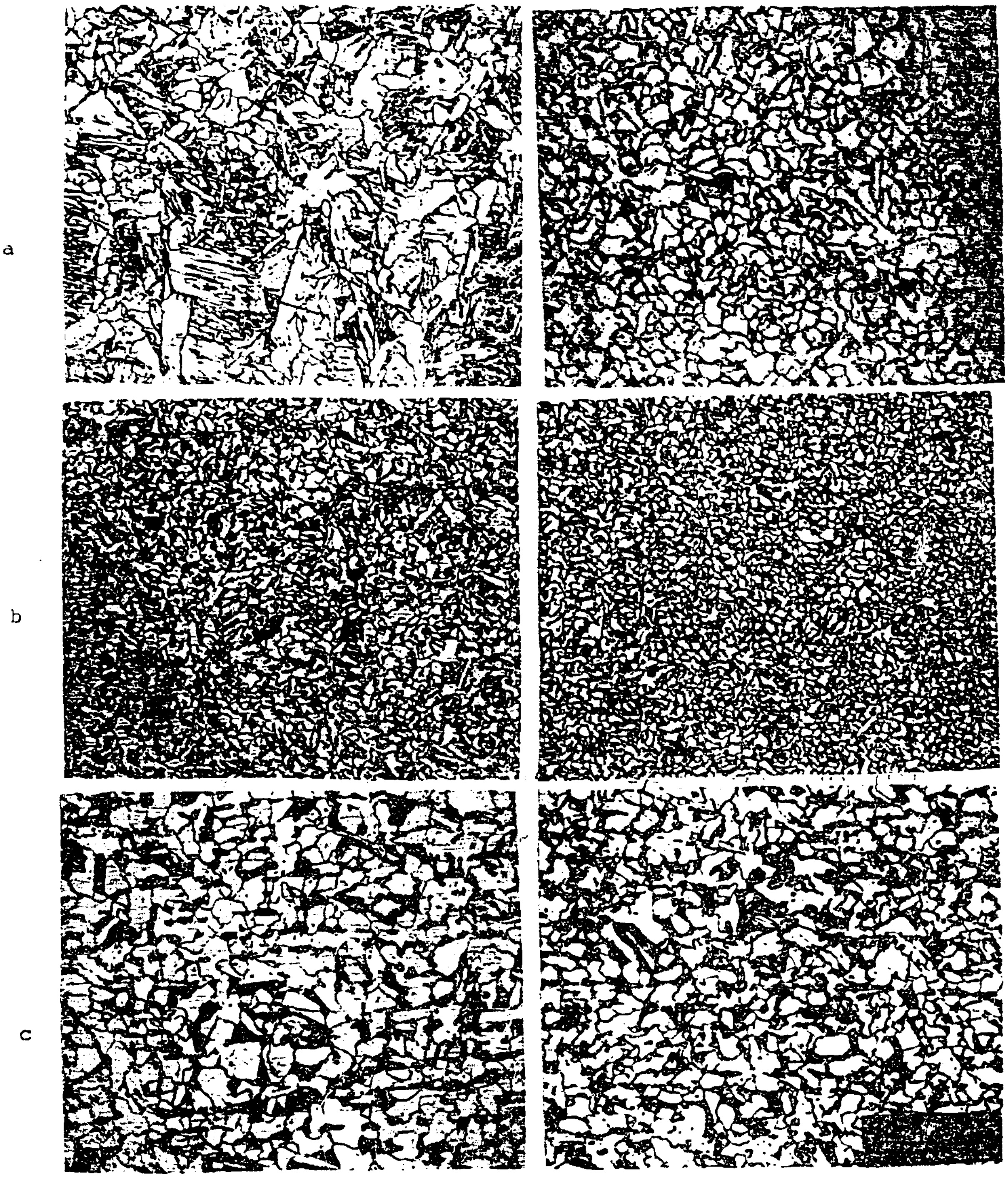


Figure 3 : Microstructure changes before and after heat treatment, in (a) Weld Zone, (b) HAZ and (c) Base Metal for as-welded (left) and after heat treatment at 600°C, 97 hrs. and water quenching (right).

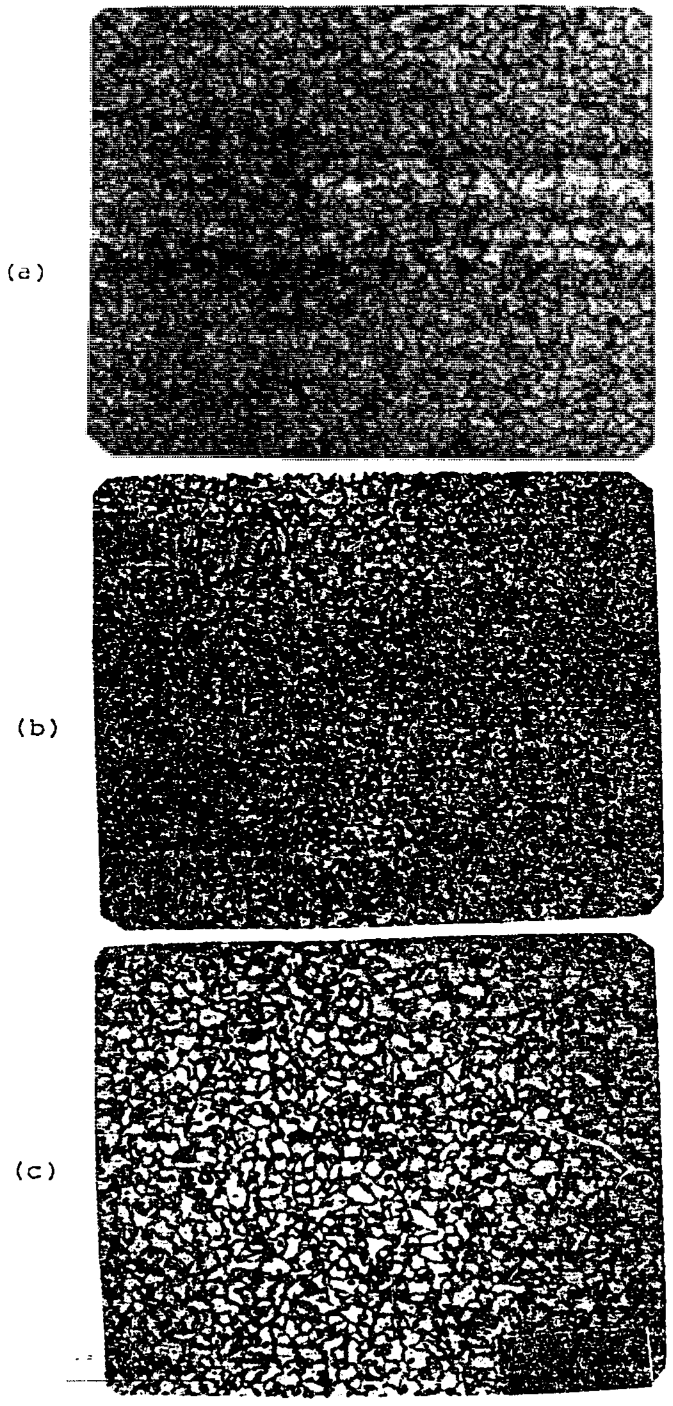


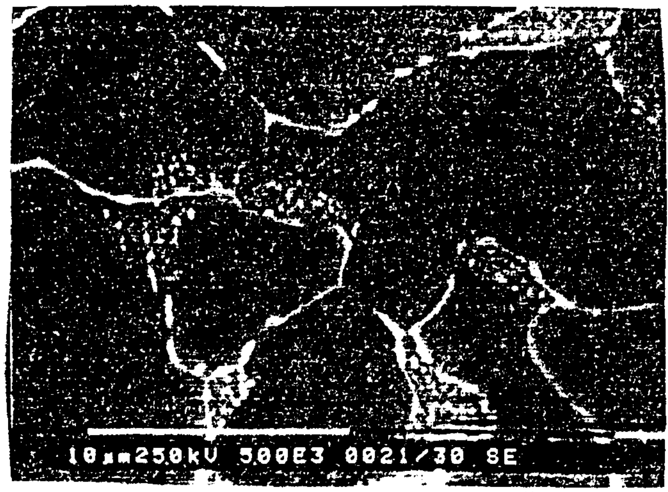
Figure 4 : Weld microstructure of carbon steel in (a) Weld Zone, (b) HAZ and (c) Base Metal after heat treatment 900°C, 1hr, AC + 900°C, 1hr, WQ and tempered at 600°C, 97hrs, WQ.

Figure 5 : HAZ

(i) as-welded (untreated).
(ii) after treatment at 600°C, 97hrs, WQ.
(iii) after treatment at 900°C, 1hr, AC + 900, 1hr, WQ and 600°C, 97 hrs, WQ.

6(i)

Figure 6(i) : Bainite & Pearlite structures in the base metal of as-welded sample.



6(ii)

Figure 6 (ii) : Heat-treated and tempered at 600°C, 97 hrs, WQ, the martensite decomposes to ferrite and carbide. Carbides present as extremely small, chunky particles rather than platelets. They were approximately spherical shape particles.

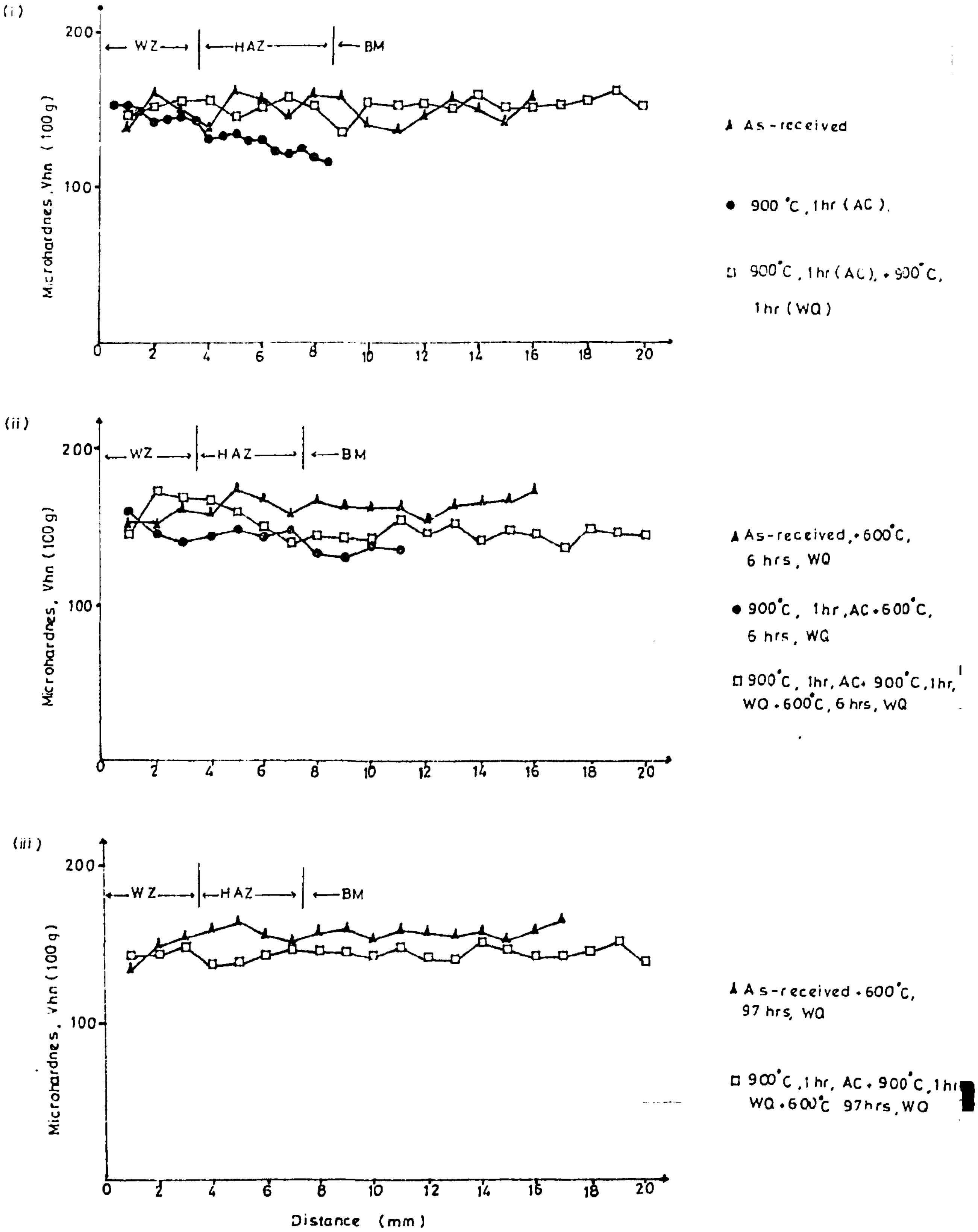


Figure (7): Variation of microhardness with distance for various heat-treatments.

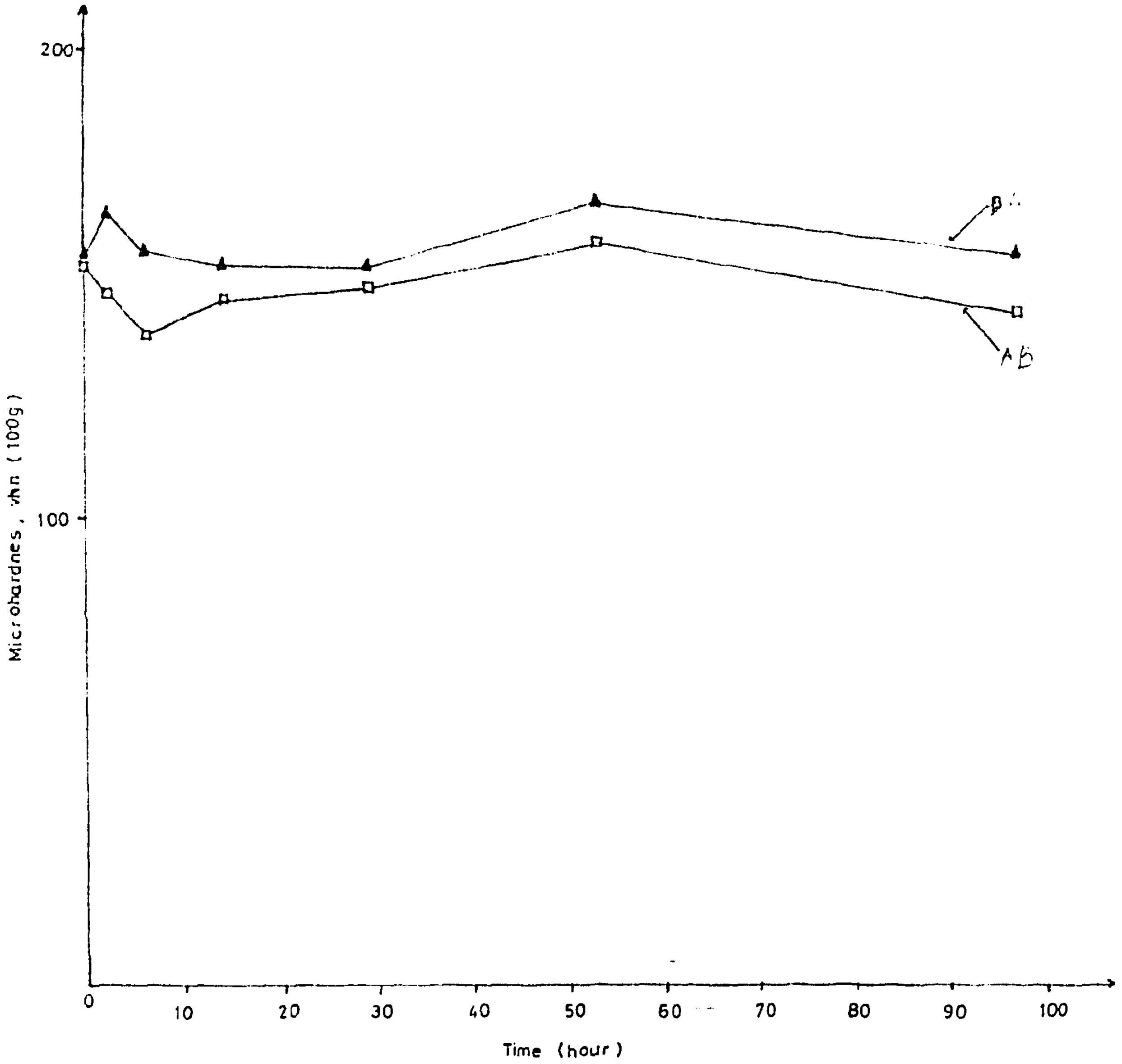


Figure (8) : The microhardness as a function of time at the same tempering temperature.

Conclusions.

1. The use of similar filler wire type is important to produce a weld metal hardness similar to that of the base metal. The correct choice of filler wire composition can produce almost any desired weld metal hardness.

2. The heat treatment alters distribution of carbide and the ferrite grain near the fusion zone. This effect can relieve the residual stress in the weldments and produce the constant hardness along the WZ, HAZ and BM.

3. Heat treatment at 600°C for 97 hours and water quenching cause refinement of ferrite grain size and produce small and spherical shapes of carbide.

4. The formation of finer grain size due to the heat treatment caused the hardness value in sample B to be higher than that of sample A.

Acknowledgements.

It is my pleasure to thank Mr. Krishnamoorthy and Mrs. Zaiton Selamat for their cooperation in metallography works and measurements of hardness.

Reference

1) Taira, T. et al, Proceedings, the 18th Mechanical Working and Steel Processing Conference, The Iron and Steel Society, American Institute of Mining, Metallurgical and Petroleum Engineers, 1976, pp. 52-86.

2) Kubota. H. et al, Proceedings, International Conference on Science and Technology of Iron & Steel, Supplemental Transactions, The Iron and Steel Institute of Japan, Vol. 11, 1971, pp. 1106 - 1110.

3) Tanake, J. et al, Transactions, The Iron and Steel Institute of Japan, Vol. 15, 1975, pp. 19-26.

4) F. Farrell and A.G. Quarrell, J. Iron Steel Inst. 202 (1964) 1002.

5) G.E. Linnert, Welding Metallurgy, American Welding Society, Vol. 2, 1967.