

An Optimal Heat Treatment Cycle for a 26Cr, 2Mo Stainless Steel

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Stainless steels containing 26Cr, 2Mo, and 1.6C are shown to contain primary and/or secondary carbides when subjected to various heat treatment routines. The soaking temperatures were found to have a pronounced effect on the types of carbides formed. It is also shown that a high volume fraction of fine secondary carbides (M23C6) results in inducing maximum hardness. Based on the results, optimal heat treatment cycles are proposed.

Keywords stainless steel, 26Cr-2Mo-1.6C steel, heat treatment

1. Introduction

Satisfactory and economical heat treatment plays an important role in the selection and development of engineering materials, and stainless steels are no exception. Such steels are normally favored for engineering applications requiring good strength at moderate temperatures and high corrosion resistance. Most grades of stainless steels are usually low in carbon (0.05 to 0.20%) but contain 4 to 18% chromium along with other alloying elements. Such steels, however, are known to have poor wear resistance.[1–4] In an effort to improve the wear resistance while simultaneously maintaining its corrosion resistance, a special grade of so-called stainless steel has been developed.[5,6] These steels have much higher chromium (above 20%) and carbon (above 1%) contents as compared with conventional stainless steels and are normally employed in the manfacturing of parts/components of specialized pumps used in the transportation of corrosive and erosive medias encountered in applications such as those listed in Table 1.

When such steels are subjected to certain heat treatment cycles (*e.g.*, Fig. 1), this results in a substantial enhancement of hardness, which subsequently deters any intermittent machining required for various manufacturing stages of pump components. On the other hand, high hardness thus achieved is desirable for adequate wear characteristics.

The present work focuses on the characterization of various carbides through systematic studies of microstructures developed as a consequence of various heat treatment cycles employed. Finally, an optimal heat treatment cycle is devised on the basis of technical and economical viability.

2. Experimental Work

For the present work, a so-called stainless steel designated as "G-X170 CrMo 25 2" per DIN 17 006 was used.[6] The samples of this steel were supplied by a leading manufacturer of pumps, who produced various heats of the following composition using an electric induction furnace:

C	Cr	Mo	Mn	Si	Fe
1.6	26.0	2.0	1.0	1.0	Bal

The samples were provided in two different conditions: one was as cast and the other heat treated. The heat treatment cycle, for the latter type of sample, is shown in Fig. 1 and consists of the following three routines:

- Routine (I): slow heating (50 °C/h) from ambient temperature to 960 °C, followed by soaking at that temperature for 18 h before furnace annealing;
- Routine (II): the furnace annealed sample is again heated (50 °C/h), from ambient temperature to 1020 °C, soaking for 10 h before normalizing (air cooling); and
- Routine (III): slow heating (50 °C/h) from ambient temperature to 280 °C, followed by soaking at that temperature for 4 h before furnace cooling.

The hardness values reported along with the cycle times for each of the above routines are summarized in Table 2.

Total time for the complete heat treatment cycle, based on all routines, amounted to approximately 100 h.

The as-cast steel samples were sectioned in order to make a number of specimens for the optimization of the heat treatment cycle. All the specimens were of identical dimensions, *i.e.*, approximately 13 × 10 × 20 mm. The specimens were heat treated at temperatures ranging from 800 to 1200 °C while using a heating rate of about 500 °C/min. A box type furnace equipped with a programmable temperature controller was used for carrying out the heat treatments. Hardness values were determined on a Vickers hardness tester using a load of 10 kg, loading time of 10 s, and loading speed of 50 m/s for all the specimens tested.

Table 1 Applications involving transportation of corrosive and erosive medias

- Flue gas desulfurization plants
- Lime washing plant
- Mining of aggressive ores
- Sewage treatment plants
- Chemical process engineering

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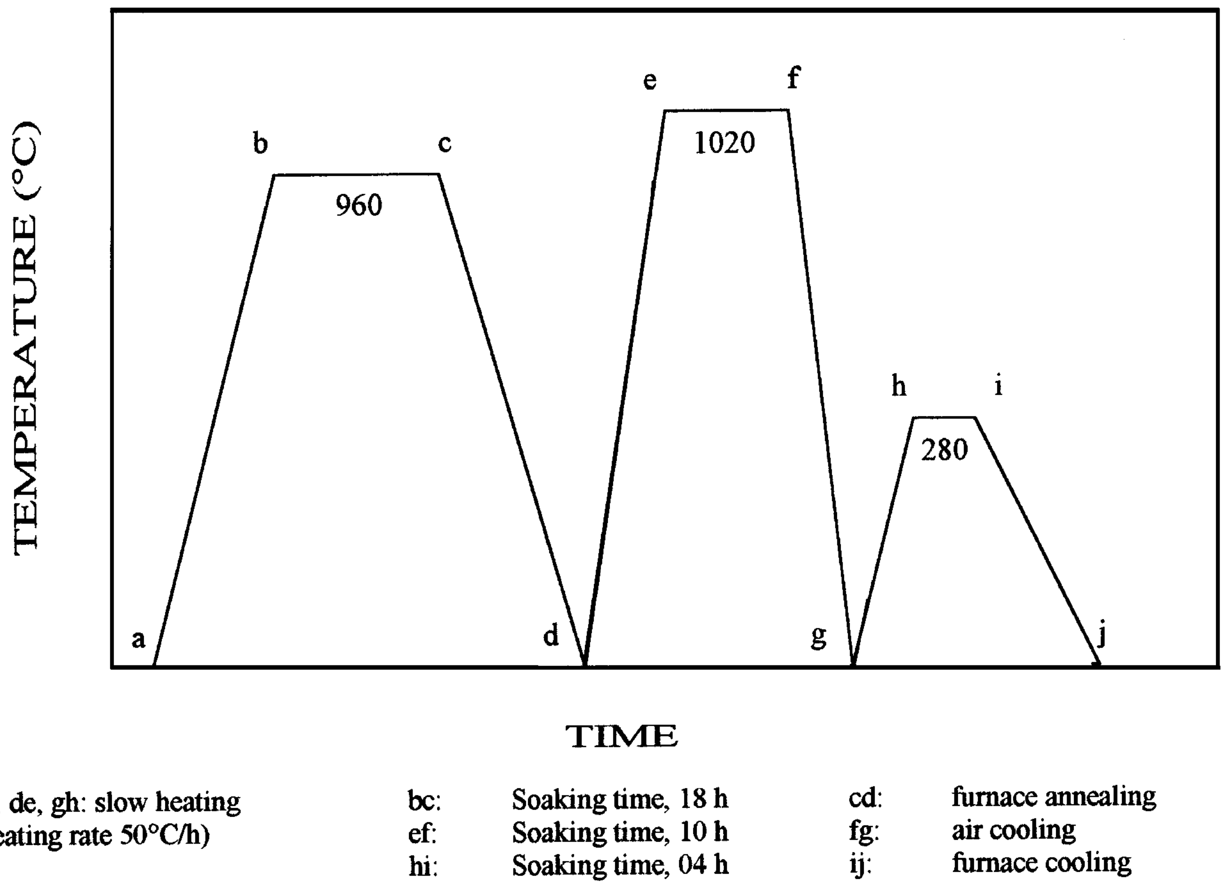


Fig. 1 Heat treatment cycle as followed by the manufacturer. The complete cycle consists of three routines (*i.e.,* abcd, defg, and ghij)

Table 2 Summary of hardness values for various heat treatment routines

Routine number	Cycle time (h)	Hardness value (VHN)
As cast	. .	>400
I	≈56	510
II	≈25	400
III	≈16	550

The average hardness values incorporating standard deviation were then used to plot the data.

An optical microscope equipped with polarized light and Nomarski interference contrast facilities was used to conduct microscopic studies. All the polished samples were ultrasonically cleaned in ethanol and etched using special etchants.[7] For detailed microstructural examination, a scanning electron microscope, equipped with an energy dispersive spectroscopy facility, was used.

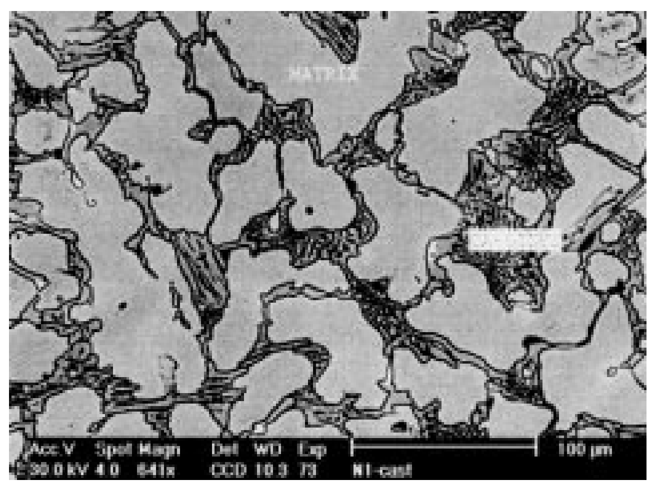
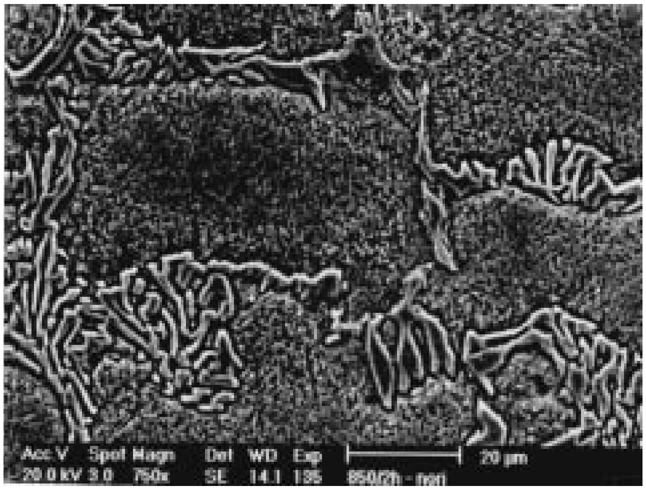


Fig. 2 SEM micrograph of as-cast alloy steel showing primary carbides (dark) in a ferritic matrix (light)

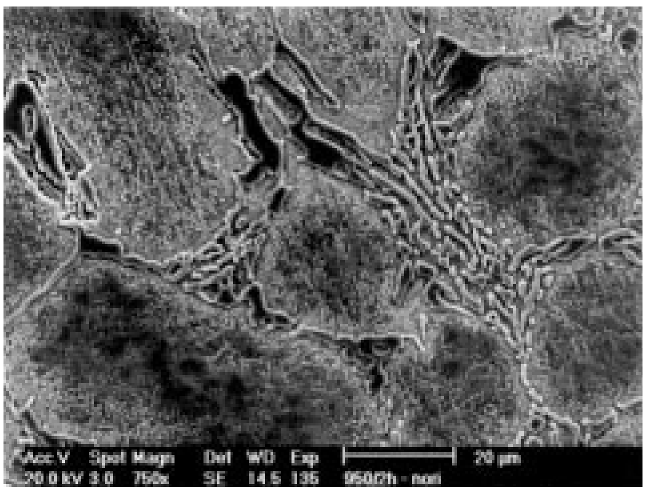
3. Results and Discussion

The material in its as-cast condition consists of a microstructure exhibiting large primary carbides between the ferritic dendrites in addition to the presence of a eutectic type structure in some areas between these dendrites (Fig. 2).

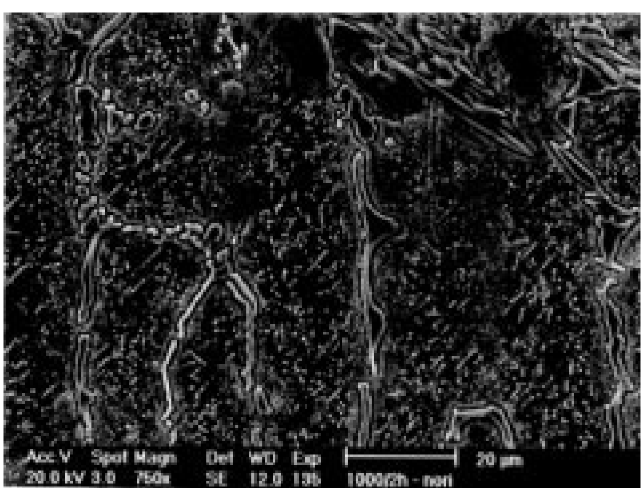
In addition to the interdenderitic primary carbides, the heat-treated samples (850 to 1000 °C) contained secondary carbides precipitated within the ferritic dendrites, as shown in Fig. 3(a) to (c). A primary carbide network was observed to be similar to that found in the as-cast samples. The primary and secondary carbides have been identified as M_7C_3 and $M_{23}C_6$, respectively, and the de-



(a)

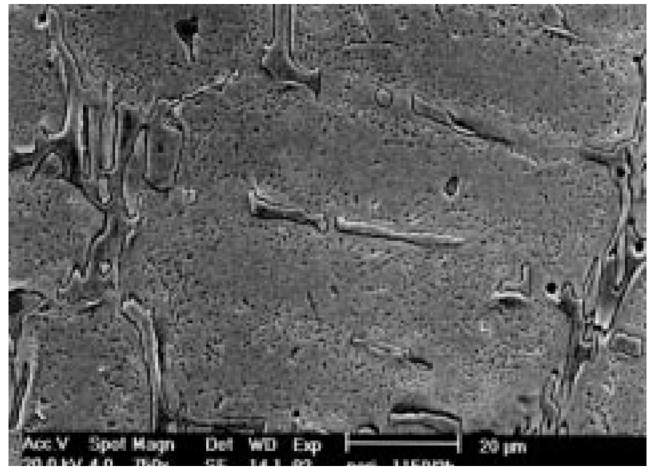


(b)

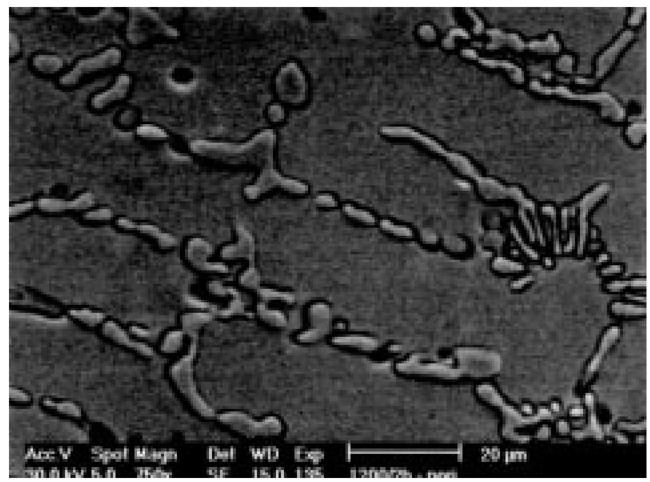


(c)

Fig. 3 Microstructures corresponding to heat treatments conducted at various temperatures: (**a**) 850 °C/2 h, (**b**) 950 °C/2 h, and (**c**) 1000 °C/2 h



(a)



(b)

Fig. 4 SEM micrographs of samples heat treated (**a**) at 1150 °C/2 h and (**b**) at 1200 °C/2 h showing gradual formation of austenite

tails are described elsewhere.[7] A gradual growth in the size of secondary carbides was evident with the increase in the heat treatment temperature. The carbides seemed to acquire maximum size in samples, heat treated at 950 and 1000 °C. In addition, austenitic phase was also observed in certain areas. Beyond 1000 °C, however, a gradual decrease in the secondary carbide volume fraction was observed, leading to their complete dissolution around 1200 °C, with concomitant formation of austenite as evident from microstructures shown in Fig. 4(a) and (b). Further, it may be seen that the volume fraction of the primary carbides also diminished significantly with increasing temperature.

The hardness values corresponding to the heat treatment routines are plotted in Fig. 5. It can be seen that a peak hardness of about 650 VHN was obtained for samples around 1000 °C, which decreased gradually beyond that temperature.

From the above observations, a correlation between the microstructure and the hardness values could be established, which indicates a strong dependence of mechanical properties on the secondary carbides. Maximum hardness can be attributed to a higher volume fraction of very fine carbide precipitates (<1 μm), which offers significant resistance to the movement of dislocations. A maximum wear resistance is also expected around this temperature, as the fine dispersion of hard particles in ferritic matrix tends to suppress both plastic dominated and brittle fracture wear mechanisms.

On the other hand, a sharp decrease in the hardness values for samples heattreated at temperatures higher than 1000 °C can be attributed to the progressive formation of austenite, which is retained after cooling to room temperature. Carbon present in the alloy is consumed by the austenite, thus suppressing the precipitation of secondary carbides.

Based on the above structure-property relationships, a schematic diagram has been devised, as shown in Fig. 6. Region I of the diagram consists predominantly of ferritic matrix embedded with primary carbides. The initiation of secondary carbide precipitation occurs in this region. The hardness tends to increase with temperature within this region. Region II, on the other hand, consists mainly of ferritic matrix, primary carbides, and high volume fraction of secondary carbides, which contribute to peak hardness values. Region III corresponds to enhanced formation of austenite and simultaneous suppression of secondary carbides, which is reflected through a gradual decrease in hardness.

From the ensuing observations, it is quite obvious that a comparatively short heat treatment cycle, as proposed in Fig. 7, could be devised to achieve the aimed characteristics, *i.e.,* good machinability for intermittent manufacturing step, while retaining high wear resistance in the end product. Subsequent to routine I (*i.e.,* abcd), the material was found to have a hardness of around 370 VHN, making it readily machinable owing to the predominant presence of austenite. Routine II (*i.e.,* efgh), on the other hand, induces required wear resistance as a result of higher volume fraction of secondary carbides.

It is pertinent to note that during the present studies, all the samples were of up to 10 mm thickness and were heated very rapidly to the soaking temperatures. The heating rates were much greater

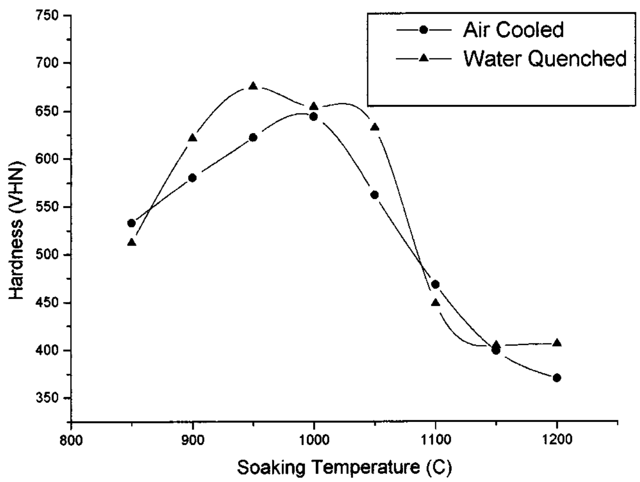


Fig. 5 Variation of hardness with increase in soaking temperature (soaking time 2 h for each treatment)

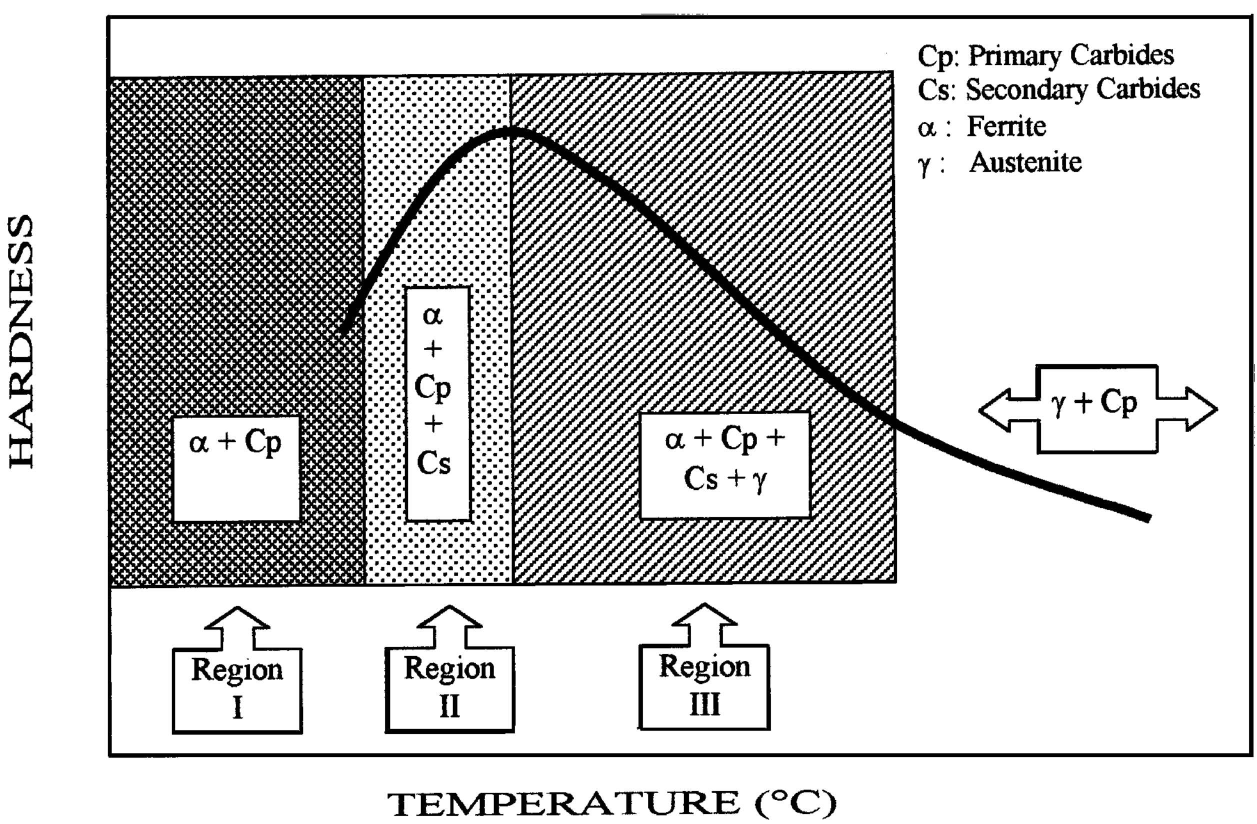


Fig. 6 Schematic diagram based on structure-property relationships developed through laboratory heat treatment experiments on the alloy steel used for the present work

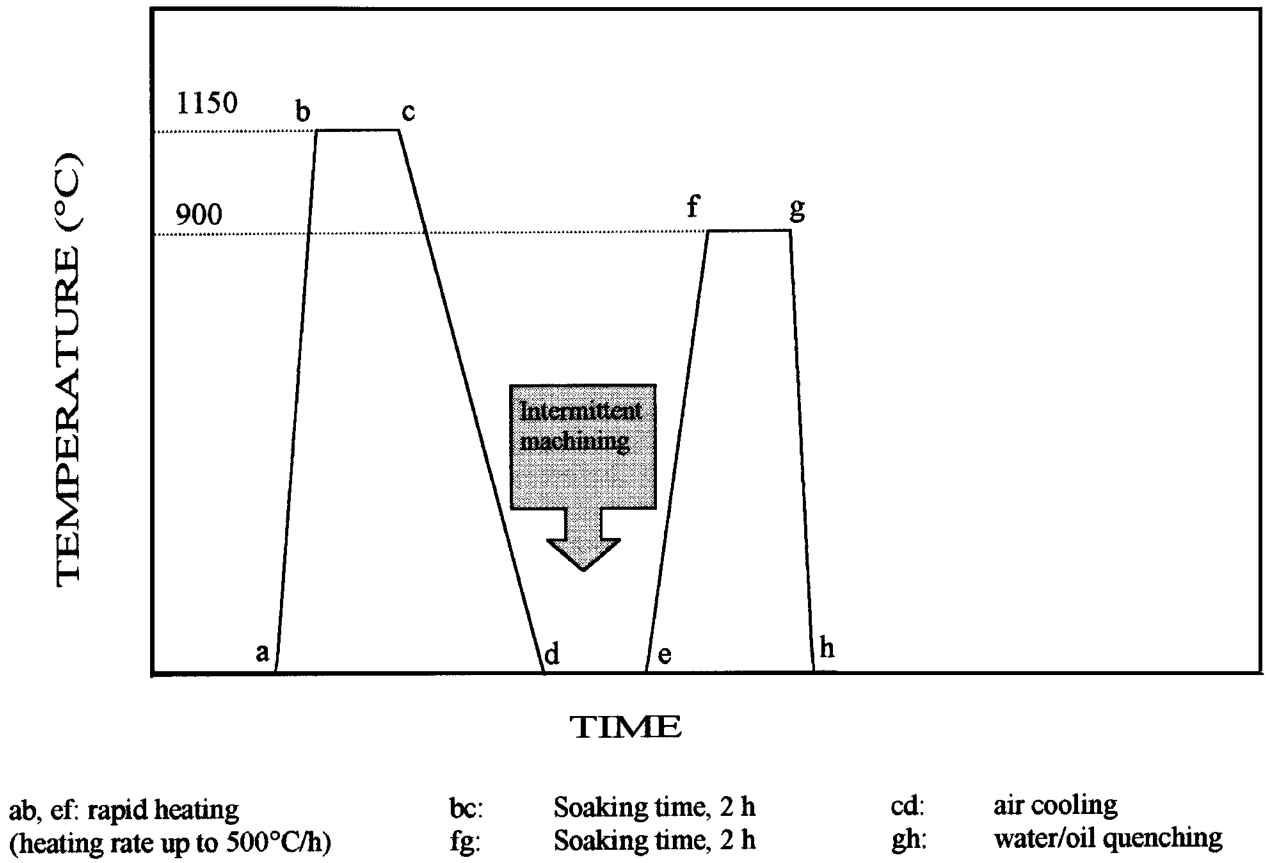


Fig. 7 Proposed heat treatment cycle based on the present work. The cycle consists of mainly two routines (*i.e.,* abcd and efgh) spreading over a total cycle time of about 10 h

than those employed by the supplier of the present samples. This does not seem to have any marked influence on the transformation characteristics of the alloy, suggesting that the heating rates could be markedly increased without any adverse effect on the uniformity of the microstructure and transformations involved. This, however, contributes in a pronounced way to the enhancement of overall economy of the heat treatment process routines.

Further, water quenching of large size samples could induce residual stresses leading to the formation of micro/macro cracks. For this very reason, it is proposed to apply air cooling or other less severe quenching media. Finally, the higher heating rate and shorter soaking times will reduce the overall heat treatment cycle by at least a factor of 10, resulting in obvious economical benefits.

4. Summary

- The microstructure in the heat-treated conditions consists of primary and secondary carbides embedded in ferritic matrix.
- The peak hardness is related to the precipitation of fine secondary carbides. The decrease in the postpeak hardness is attributed to suppression of secondary carbides owing to the progressive formation of austenite.
- The high heating rates do not seem to have any adverse effect on the uniformity of microstructure and could be safely employed.
- The production efficiency, and economical advantages are obvious outcomes of the proposed heat treatment cycle.

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