The Influence Of Microstructure On The Corrosion And Wear Mechanisms Of High Chromium White Irons In Highly Caustic Solutions

G. D. Nelson

School of Mechanical Engineering
The University of Adelaide
South Australia

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Appendix A

Heat Treatment Study

A heat treatment study was carried out to determine the optimum heat treatment temperature (destabilization temperature) to give maximum hardness for the HyperA alloy. The heat treatments were done for 6 hours followed by furnace cooling using the methods described in the Equipment and Test Methods section. Bulk Vickers hardness tests and optical microscopy of the heat treated samples were done on metallographically prepared samples. The heat treatment temperatures ranged from 800ºC to 1150ºC in 50ºC increments.

Table A.1 and Figure A.1 show the results of the heat treatment study from 800ºC to 1150ºC in 50ºC increments. The heat treatment at 800ºC is found to increase the bulk hardness by about 60 points over the as-cast condition. The bulk hardness further increases with soak temperature up to 950ºC where the bulk hardness is maximized at about 890 HV_{30}. A further increase in soak temperature to 1000ºC reduces the bulk hardness by about 40 points. The bulk hardness continues to decrease with every 50ºC increase in soak temperature with the lowest bulk hardness at 1150ºC which is over a 100 points below the as-cast condition.

Table A.1: Variation in the bulk hardness of HyperA casting with different heat treatment temperatures.

Soak Temperature (°C)	Bulk Hardness (HV_{30}) ± Standard Deviation
As-cast	682 ± 20
800	739 ± 13
850	768 ± 14
900	829 ± 20
950	890 ± 12
1000	851 ± 10
1050	752 ± 11
1100	612 ± 15
1150	577 ± 14

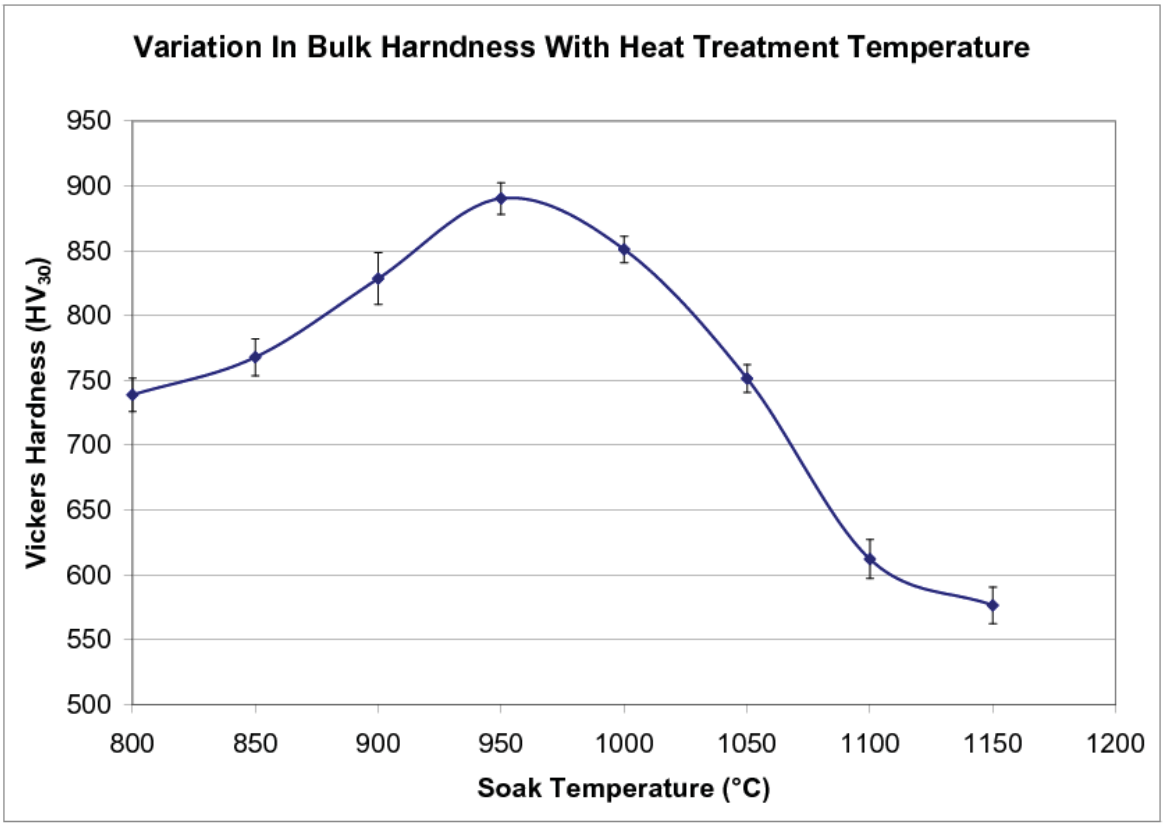


Figure A.1: Graph of the variation in the bulk hardness of HyperA casting with different heat treatment temperatures.

Optical micrographs of the heat treated samples are shown in Figure A.2. The micrographs show that at the lower soak temperatures there is extensive secondary carbide precipitation, which is shown by the dark regions in the micrographs. As the soak temperature is increased the proportion of secondary carbides decreases, but the size of secondary carbides increases, up to 1100°C. The heat treatment at 1150°C results in negligible secondary carbides and a matrix almost entirely composed of austenite. All of the heat treated samples were attracted to a magnet which indicates the presence of martensite in the matrix including the sample heat treated at 1150°C.

The effect of heat treatment temperature on the bulk hardness is similar to what has been previously reported in the literature (Maratray and Poulalion, 1982, Pearce, 1984). The maximum hardness is attributed to a combination of acceptable retained austenite contents and a high content of high carbon martensite. At low heat treatment temperatures the retained austenite level is low due to the extensive precipitation of secondary carbides that significantly reduce the carbon and chromium content of the matrix and raises the martensite start temperature above room temperature. However, due to the lower carbon content of the austenite, the transformed martensite is not as hard and gives a lower bulk hardness. At high heat treatment temperatures the solid solubility of carbon and chromium in the austenite is increased and the driving force for secondary carbide precipitation is reduced. On cooling, higher proportions of retained austenite occur as little of the austenite transforms to martensite as the increased carbon content causes a significant reduction in the martensite start temperature. A lower bulk hardness is the result of higher heat treatment temperatures.

In summary, for the HyperA alloy, the maximum hardness is achieved at a heat treatment temperature of 950^{o}C and a near fully austenitic matrix with very limited secondary carbide precipitation is achieved at a heat treatment temperature of 1150^{o}C.

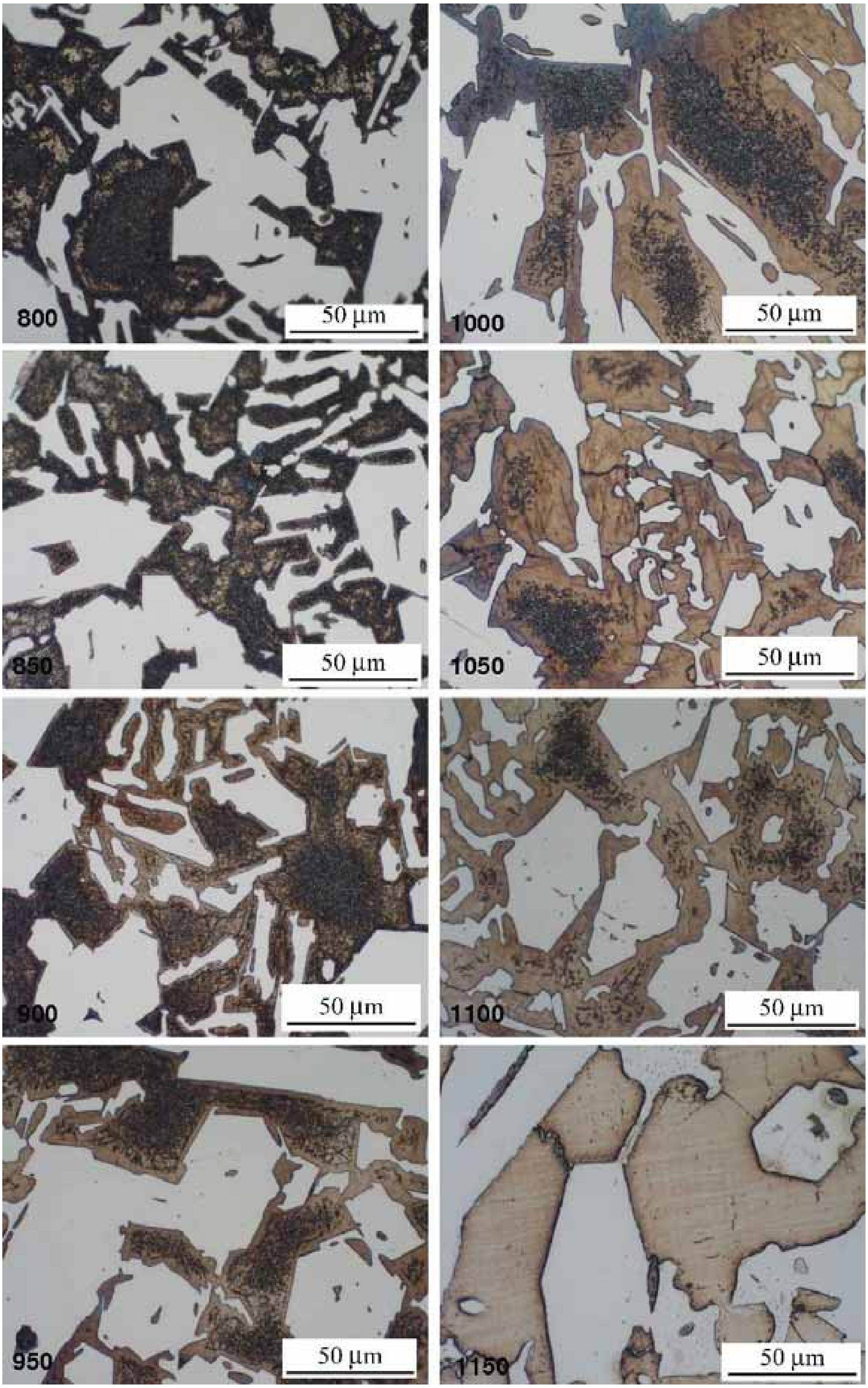
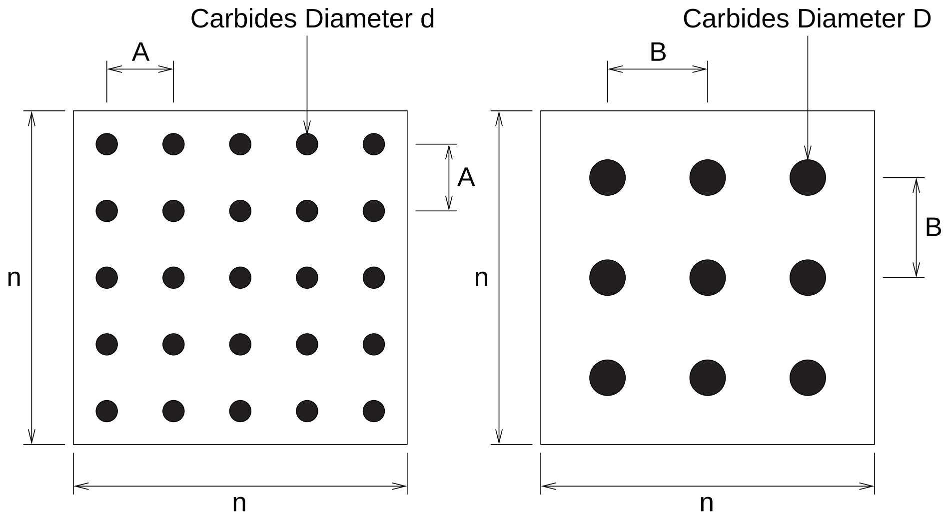


Figure A.2: Optical micrographs of the HyperA casting after heat treatment at temperatures from 800 to 1150°C. All micrographs 500x magnification.

Appendix B

CVF, Carbide Spacing and Exposed Surface Area

Relationships between CVF, the size of carbides, the number of carbides and the inter-carbide spacing can be developed by considering an area n by n of small carbides having an effective diameter d and larger carbides having an effective diameter D shown in the figure below.



Where:
d is the diameter of the small carbides
D is the diameter of the large carbides
X is the number of small carbides
Y is the number of large carbides
A is the spacing between the small carbides
B is the spacing between the large carbide
n is the area considered

Considering the small carbides, the relationship between carbide size and CVF is given by Equation B.1.

$$X\frac{\Pi}{4}d^2 = n^2.CVF \tag{B.1}$$

Likewise for the large carbides, the relationship between carbide size and CVF is given by Equation B.2.

$$Y\frac{\Pi}{4}D^2 = n^2.CVF \tag{B.2}$$

For the same CVF, Equation B.1 and B.2 are equal.

$$X\frac{\Pi}{4}d^2 = Y\frac{\Pi}{4}D^2 \tag{B.3}$$

The diameter of the large carbides will be a factor of the small carbides, Equation B.4.

$$D = \lambda d \ or \ \lambda = \frac{D}{d} \tag{B.4}$$

Substituting Equation B.4 into Equation B.3 gives Equation B.5, which reduces to B.6

$$X\frac{\Pi}{4}d^2 = Y\frac{\Pi}{4}\left(\lambda d\right)^2 \tag{B.5}$$

$$X = Y\lambda^2 \tag{B.6}$$

Therefore, the number of small carbides compared with the number of large carbides is the squared value of the ratio of large carbide diameter to small carbide diameter or $\lambda^2 \ (where \ \lambda \geq 1)$.

A similar methodology can be used to develop a relationship for the inter-carbide spacing by considering the grid of carbides shown above with equal spacing in both directions over an area n by n. For the small carbides, the spacing is given by Equation B.7.

$$A = \frac{n}{\sqrt{X}} \tag{B.7}$$

Likewise for the large carbides, the spacing between carbides is given by Equation B.8.

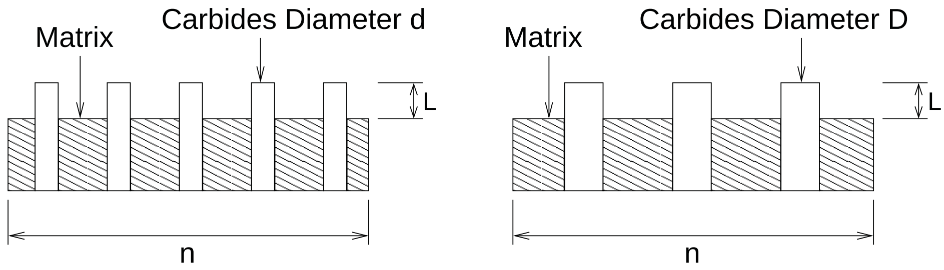
$$B = \frac{n}{\sqrt{Y}} \tag{B.8}$$

Substituting Equation B.6 into Equation B.7 gives Equation B.9.

$$A = \frac{n}{\sqrt{Y}.\lambda} \ or \ A = \frac{1}{\lambda}B \tag{B.9}$$

Therefore, the spacing between the small and large carbides is $\frac{1}{\lambda} = \frac{d}{D}$ or the ratio of the small carbide diameter to the large carbide diameter.

The relationship between the exposed surface area of carbides of different diameter can be developed by considering the cross section of the ideal grid of carbides considered above as shown in the figure below.



Where:

L is the distance that the matrix is recessed with respect to the carbides

The surface area of the exposed carbide rods for the small carbides is given by Equation B.10. Note, the equation only considers the surface area exposed on the side of the carbide rods and has excluded the tip surface area which is constant for a given CVF.

$$SA_S = X\Pi dL \tag{B.10}$$

Likewise the surface area of the exposed carbide rods for the large carbides is given by Equation B.11.

$$SA_L = X\Pi DL \tag{B.11}$$

Substituting Equation B.6 into equation Equation B.10 gives Equation B.12

$$SA_S = Y\lambda^2\Pi dL \tag{B.12}$$

$$= Y\frac{D^2}{d^2}\Pi dL \;\; as\ \lambda = \frac{D}{d}$$

$$= Y\Pi DL\frac{D}{d}$$

$$Therefore\;\; SA_S = \lambda SA_L$$

Therefore the exposed surface area of the small carbide rods is greater than the exposed surface area of the large carbide rods by the ratio of large carbide diameter to small carbide diameter or $\lambda\ (where\ \lambda \geq 1)$.