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DISCUSSION

R. Blondeau[1] *(written discussion)*—I am not sure that your proposal of changing the tempering temperature from 630°C to 640°C will be a good one. The industrial furnaces in which the shells are treated cannot have the precision of a laboratory furnace on all points. And, you show that a 650°C tempering will be detrimental, due possibly to all other embrittling phenomena, which is irreversible, and worse.

A. A. Tavassoli (author's response)—We agree with Mr. Blondeau's remark that temperature control in industrial furnaces is more difficult than in laboratory furnaces. Our proposal is also intended to guide the furnace operator during his temperature setting. For instance, that means that 630°C+ is better than 630°C−.

R. L. Bodnar[2] *(written discussion)*—You indicated that the toughness of A 508-84a Class 3 forgings could be increased by raising the austenitizing temperature from 875 to 900°C, thereby increasing the degree of homogenization (eliminating the microsegregation regions) and suppressing temper embrittlement in the steel. I have an alternative recommendation. I would increase the normalizing temperature or time of the preliminary heat treatment or both to improve homogenization. I would also maintain the lower austenitizing temperature of 875°C to refine the prior austenite grain size, which would be expected to further enhance toughness.

A. A. Tavassoli (author's response)—Mr. Bodnar's suggestion is in line with our findings that improved homogenization reduces the risk of temper embrittlement. We agree that it is preferable, when possible, to achieve this through improved intermediate heat treatment. However, it should be recalled that the actual prior heat treatment temperature used in industry is higher than the final heat treatment (875°C) and is between 900 and 950°C.

W. R. Warke[3] *(written discussion)*—The onset of temper embrittlement susceptibility of 2¹/₄Cr-1Mo pressure vessel steels has been successfully related to a factor attributed to Watanabe

$$J = (\mathrm{Mn} + \mathrm{Si})(\mathrm{P} + \mathrm{Sn}) \times 10^4$$

This factor reflects the observation that manganese promotes phosphorus segregation. In view of the high manganese content of your steels, I wonder if this factor or a similar one, could be used to correlate your data.

A. A. Tavassoli (author's response)—In order to be able to correlate J values with variations in manganese, silicon, and tin contents, a large number of test data obtained from several heats are needed, which we do not have. To answer the question, we can add that the current manganese specification for A 508-84a Class 3 steel is between 1.12 and 1.58% and the steel used in our investigation has about 1.36% manganese. Furthermore, the plate material that is used in our study has 1.46% manganese and is less sensitive to temper embrittlement than the forged material.

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