the stress to cause 1 percent creep in 100,000 hr, A302B is superior to A533A. Similarly, A302C has superior creep and rupture properties to those of A533B. However, the rupture ductility of the quenched and tempered grades exceeds that of the normalized and tempered grades.

Notch Toughness

In addition to the evaluation of the tensile and creep rupture properties of Mn-Mo and Mn-Mo-Ni steels, an evaluation of the susceptibility of each grade of steel to classical temper embrittlement was made. The tensile data for the as-tempered and step cooled conditions are listed in Table 5. Table 6 contains the fracture appearance transition temperature (FATT), energy absorbed at the FATT (\(E_{\text{FATT}}\)), 40 ft-lb transition temperature (TTFe), energy absorbed at 50 deg F (\(E_{50}\)), and the upper shelf energy (\(E_{\text{us}}\)) data. Fig. 10 shows the trends in FATT.

Step cooling caused a slight drop in the tensile and yield properties of the normalized and tempered conditions (A302B, A302C). The ductility either remained the same or increased slightly. In the quenched and tempered grades (A533A, A533B) the yield and tensile strengths are not affected as much by step cooling as are the normalized and tempered grades. Also, the ductility is slightly decreased as a result of step cooling.

The data in Table 6 and Fig. 10 show that the notch toughness is not greatly affected by step cooling. There is no appreciable difference in the susceptibility to temper embrittlement caused by Ni in the normalized and tempered grades (A302B, A302C). However, there is a difference in the susceptibilities between A533A and A533B. Nickel apparently increases the susceptibility in the quenched and tempered condition. The FATT in A533B shifts a total of +60 deg F upon step cooling whereas the shift in A533A is +20 deg F. However, the absolute FATT for embrittled A533B is -20 deg F which is generally acceptable.

Conclusions

The major conclusion that can be drawn from this work is that Ni impairs the elevated temperature properties of Mn-Mo steels. Regardless of the heat treatment, the rupture strength of Mn-Mo ranges from 14~50 percent higher than for Mn-Mo-Ni at 850 deg F. Although still superior at 950 deg F, Mn-Mo does not have this large a strength advantage. Material normalized and tempered to the A302B or A302C specification has better creep properties than the corresponding quenched and tempered A533A or A533B grades.

Tensile and creep ductility are improved by the addition of Ni. This is a fairly large effect but does not offset the disadvantage of the effect of Ni in reducing the rupture and creep resistance. Of the two types of heat treatments used, the quenched and tempered condition has the greater ductility.

Experience with heavy gage Mn-Mo and Mn-Mo-Ni steels has demonstrated the distinct advantage of Ni in improving hardenability and notch toughness. However, the nature of the tests performed during this study has precluded such a comparison. Since the orientation of the Mn-Mo-Ni impact specimens with respect to the rolling direction is unknown, quantitative comparisons cannot be made. However, a comparison of the effect of Ni on the susceptibility to temper embrittlement can be made. Quenched and tempered Mn-Mo-Ni (A533B) appears to have a greater susceptibility than does similarly treated Mn-Mo (A533A) although both grades have good notch toughness for the heat treatments used.

References


DISCUSSION

E. V. Bravenec

The discusser would like to congratulate the authors for supplying some very pertinent data in an area of current interest. The comments are in the form of suggestions that the discussion feels will enhance the value of the data presented in this paper.

1. The discusser cannot find any reference to the grain size which he feels is most important. This could be defined by including a total or soluble aluminum analysis in Table 1. The notch toughness would, of course, be affected by grain size and since these grades are made both fine and coarse grained, this point should be clarified.

2. The use of production heats for experimental work is very good; however, the variables must be controlled very carefully. Heats "C" and "D" for instance were drop offs from spun heads and rolling direction was unknown. The discusser feels that rolling direction is a very important variable and must be known to enable one to compare properties, heat treatments, etc. Also closely associated is the amount of cross-rolling which is not mentioned but is very influential, especially on notch toughness properties.

3. Sample orientations were also not mentioned—such as OVM, L or T? This could explain the abnormal properties of heat "C".

With the above mentioned suggestions more fully explained, the discusser feels that the authors' data are valuable contributions to the literature of these grades.

Author's Closure

The steels used in this study had grain sizes in the range of ASTM 5~7. All four heats were aluminum treated, but no attempt to analyze for soluble and insoluble aluminum was made. It is recognized that the notch toughness values for the two Mn-Mo-Ni steels are not definitive of the notch toughness of this steel. This is attributable to the fact that tests were performed on rim stock from spun heads and specimen orientation is not known. However, tests on the parent plates showed that the notch toughness ranged from 54 to 81 ft-lbs at 10 deg F.

The lack of knowledge about rolling direction is not critical for the purposes of this investigation. First of all, the primary purpose of the notch toughness data is to evaluate the susceptibility to classical temper brittleness. Susceptibility is a relative factor and can be measured on specimens with any orientation so long as all treatments and tests are performed on the same orientation. Mn-Mo and Mn-Mo-Ni steels have been extensively studied for notch toughness in as-heat treated conditions and there is no great need for that data. The need for data is more pressing in the area of elevated temperatures. Since tensile and creep properties are not strongly dependent upon orientation, valid comparisons between compositions can be made.

The effects of the trap elements As and Sb were not studied in this investigation. Analyses for these elements in the two Mn-Mo-Ni steels were made but no clear trends were observed. Both heats show similar susceptibilities and have comparable impurity content. Using the embrittlement factor (X) developed by Mr. Bruscato (Res. Sup. to Weld. J. Apr. 1970) Heat C has an X factor of 18.3 and Heat D has an X factor of 20.2.

1 Armco Steel Corporation.