DETECTION OF TEMPER EMBRITTLEMENT IN STEELS USING MAGNETIC INSPECTION METHODS

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INTRODUCTION

This paper reports on a series of investigations of the effects of temper embrittlement on the magnetic properties of three different groups of steels. The objective of the work was to determine whether temper embrittlement caused any significant changes in the bulk magnetic properties and whether these changes could be incorporated into a nondestructive evaluation technique for assessment of temper embrittlement.

The results of this investigation showed that there are excellent prospects for future utilization of magnetic NDE methods for monitoring the progress of temper embrittlement in steels.

The temper embrittlement problem

Temper embrittlement of alloy steels [1,2] presents a problem because of the increased likelihood of failure due to the reduced toughness of structural components which have been exposed to temperatures in the range of 400 - 600°C over extended periods ranging from a few hours to days. The temper embrittlement is due primarily to segregation of impurity/strengthening elements at the grain boundary [3]. This occurs during austenitization or tempering and the segregation occurs at the prior austenite grain boundaries. Steels that have been subjected to temper embrittlement can be restored to their original toughness by heating above 600°C and then rapidly cooling to below 300°C. Evidence of restoration of the magnetic properties of specimens of HY80 steel heated above 621°C was noticed in this investigation.

The fracture in a temper embrittled steel is intergranular and therefore the fracture propagates along the prior austenitic grain boundaries, although the fracture actually initiates on the ferrite-cementite interfaces. The susceptibility to temper embrittlement is dependent on chemical composition, and is enhanced by the presence of chromium and manganese. The chief embrittling elements which migrate to the boundaries are antimony, phosphorus, tin and arsenic. It should be noted that plain carbon steels with less than 0.5 wt% Mn do not suffer from temper embrittlement.

Rationale for the use of magnetic methods

Previous studies have shown that the bulk magnetic properties of steels are sensitive to changes in chemical composition and microstructure [4,5]. For example the presence of second phase particles within a steel with different magnetic properties from the matrix material, can act as pinning sites for Bloch walls. Impurity elements alone can also impede domain wall motion. Although these effects are usually of secondary importance compared with the second phase particles. Nevertheless in purer materials which do not have a second phase per se, the impurity elements can form one of the principal obstacles to domain wall movement. Thus in steels, not only the cementite phase, but also small amounts of undissolved carbon can cause increases in coercivity.

It is therefore clear that small amounts of impurity elements can have an effect on the structure sensitive magnetic properties which is far greater than their proportion in the material. Furthermore the distribution of these impurities also affects the magnetic properties. As an example, it is known that impurity strengthening elements when distributed throughout a steel can lead not only to an increase in yield strength, but also to an increase in coercivity. When these elements begin to segregate the yield strength is reduced and the coercivity undergoes a concomitant decrease. Therefore the use of the coercivity or related magnetic properties would seem at first sight to hold good prospects of success in the evaluation of temper embrittlement.

Experimental details

In this work we have investigated changes in the magnetic properties of several different grades of steel under different temper embrittlement conditions. The discussion here will focus on the results obtained on a group of low alloy 3.5NiCrMoV steels (ASTM-A471) which were heat treated to two different yield strengths and then temper embrittled, and on a group of HY-80 high strength steels which were initially nominally identical and were then subjected to temper embrittlement for different times and temperatures.

The specimens were supplied in their heat treated and temper embrittled conditions. Magnetic measurements were made to determine the structure sensitive magnetic properties such as coercivity, permeability, remanence and hysteresis loss. The effects of temper embrittlement on these properties were then determined with the objective of identifying those magnetic properties which could usefully be used for nondestructive evaluation of the condition of temper embrittlement.

RESULTS

Chemical analyses of the ASTM A471 steels were made and these revealed the following compositions: Ni 3.3 wt%, Cr 1.57 wt%, Mo 0.36 wt%, Mn 0.3 wt%, C 0.29 wt%, V 0.09 wt%, Si 0.07% with other constituents of copper, phosphorus and sulphur less than 0.05 wt%. The measured grain sizes in these specimens were ASTM GS 3 (25%), ASTM GS 4 (30%) and ASTM GS 5-8 (45%).

Chemical analyses of the HY-80 specimens were made giving the following compositions: Cr 1.46 wt%, Ni 2.77 wt%, Mn 0.68 wt%, Mo 0.43 wt%, Si 0.36 wt%, C 0.15 wt%, Cu 0.13 wt%. All other chemical constituents amounted to less than 0.05 wt%.

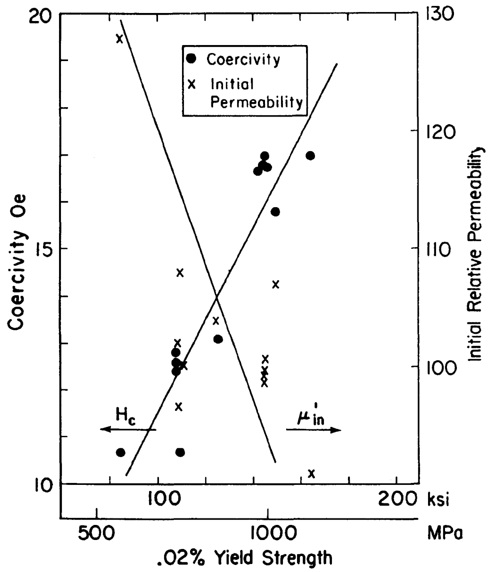

Fig. 1. Dependence of coercivity and initial permeability on yield strength of ASTM A471 steel.
o Coercivity x Initial permeability.

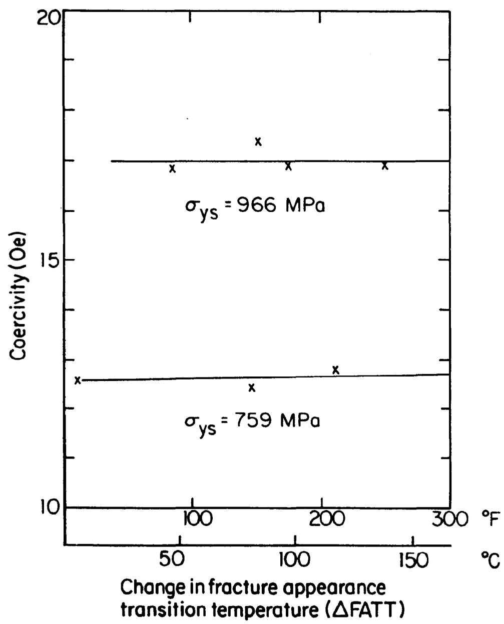

Fig. 2. Variation of coercivity with temper embrittlement of ASTM A471 steel as measured by the change in fracture appearance transition temperature Δ FATT.

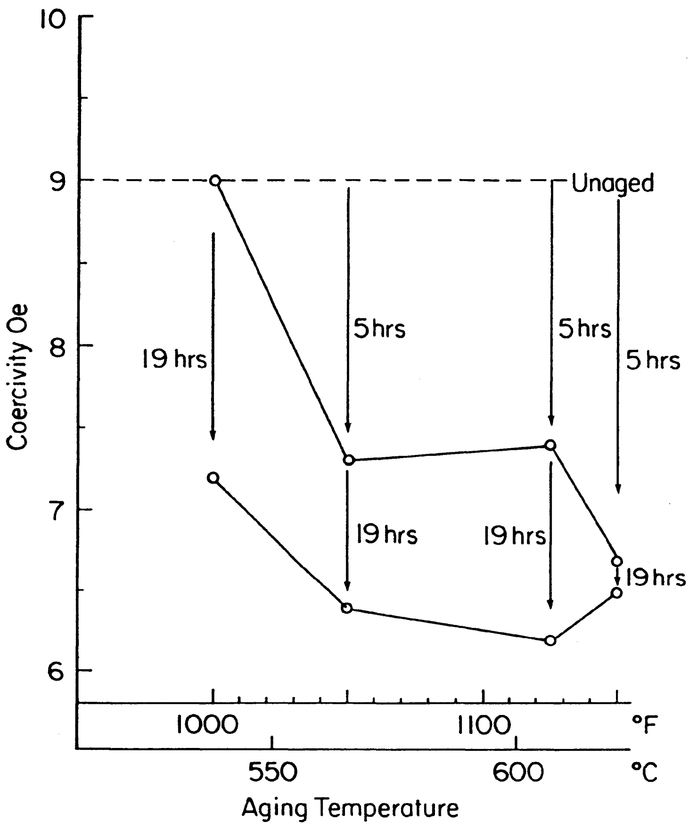

Fig. 3. Dependence of coercivity on aging time and temperature for HY-80 steel.

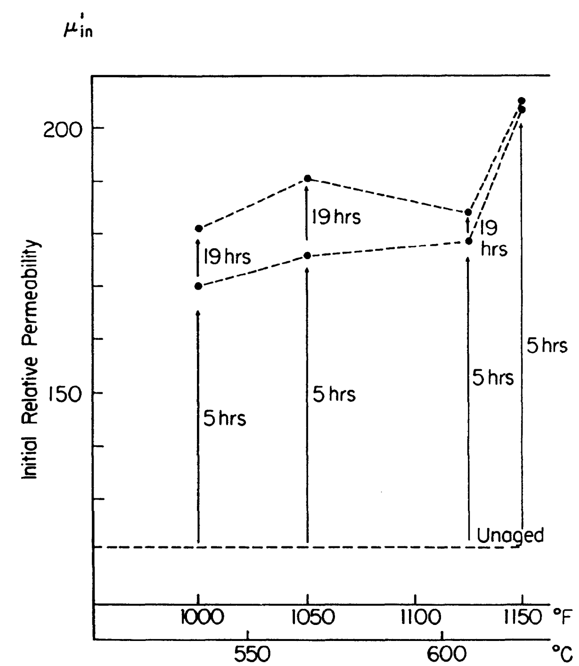

Fig. 4. Dependence of initial permeability on aging time and temperature for HY-80 steel.

The magnetic properties of the ASTM-A471 group materials were measured using a multiparameter magnetic inspection system [6]. We summarize here the most important of these results. It was found that the initial permeability and coercivity varied with yield strength as shown in Fig. 1. Nevertheless they were found to be independent of the temper embrittlement as measured by the change in fracture appearance transition temperature ΔFATT, as shown in Fig. 2. It therefore appears that little change is seen in the magnetic properties as a function of temper embrittlement in this material.

In the HY-80 steels however the situation was quite different with significant changes in coercivity and initial permeability as a function of both time and temperature during temper embrittlement, as shown in Figs. 3 and 4. The reduction in coercivity here is considered to be due to the segregation of impurity strengthening elements at the grain boundaries, which reduces the amount of domain wall pinning, leading in addition to higher initial permeability.

CONCLUSIONS

Magnetic methods present a good prima facie case for a viable NDE technique for detection of temper embrittlement. Results obtained in the present investigation were very promising for HY-80 steels, but less encouraging for ASTM-A471 steels. In the former case large progressive changes in coercivity and initial permeability were observed with both time and temperature during the embrittlement process. These changes can be attributed to a reduction in the impedance to domain wall motion as the embrittling process proceeds. In the latter case the changes with temper embrittlement were too small to be useful as an NDE technique for temper embrittlement. On the other hand the variation of magnetic properties with yield strength indicated further potential for nondestructive evaluation of yield strength.

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