Eddy current detection of changes in stainless steel after cold reductions

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Abstract

Cold rolling of austenitic stainless steel results in increase of residual stresses, hardness, and tensile strength and dislocation density. We have studied the response of eddy current impedance to austenitic change, hardness and its lift off phase in stainless steels during cold reductions. A series of samples of austenitic stainless steel alloys were cold rolled and found that only percentage variation in austenite affects the eddy current flow and its lift off phase.

Keywords: eddy current, cold rolling, austenite

1. Introduction

Austenitic stainless steels have an austenitic face centered cubic (FCC) microstructure at room temperature. They cannot be hardened by heat treatment. They can, however be considerably strengthened by cold work. Cold working of steels produces an inhomogeneous structure which is responsible for strain hardening of the alloy. This structure also has a crucial effect on the formation of new grains during the process of recrystallisation.

Austenitic stainless steel alloys have dominant position mainly because of their high corrosion resistance and formability and thus they possess highly desirable properties for many engineering applications. AISI 304, AISI 321, AISI 316L and 12Ch21NG2STL (Gost) are most widely used stainless steels. Austenitic stainless steel alloys can be classified into two groups according to the stability of austenite in the microstructure: stable austenitic and metastable austenitic. The stable austenitic steels microstructure remains austenitic after cold working. The structure of metastable austenitic stainless steel is transformed up to some degree by cold working so that a mixed martensitic-austenitic structure is developed [!-3].

Several authors have carried out eddy current measurements on austenitic stainless steel. D.O'Sullivan and al [4], used the techniques including the use of magnetic Barkausen noise, ferromagnetic phase measurement and corecivity measurements and B.P.C.Rao and al [5], has used artificial neural network which implements multi-frequency multi-parametric eddy current test for on- line depth quantification of surface breaking defects in austenitic stainless steel welds in the presence of disturbing weld variations, lift- off and edge effect but no one has touched austenitic variation with the eddy current response.

We have investigated here the influence of several parameters like eddy current impedance response, to hardness and its lift off phase during austenite variation as a function of cold rolling. It has been noted that the eddy current impedance values are sensitive to austenitic stainless steels as a function of cold reductions and this measurement technique can be easily utilized for a non contact / contact NDE of material emerging from a production line.

Eddy current method has been used to determine volume percentage of austenite in the maraging steel [6].and to sort out maraging steel components with undesirable microstructure [7].

2. Experimental set up

The basic motive behind this study is as follows. When a probe coil, excited with alternating current, is placed on an electrically conducting material such as stainless steel, eddy currents are induced in the material. Variation in conductivity, magnetic permeability and microstructure of the sample disturbs the eddy current flow and in turn alters the coil impedance. These changes in impedance are usually correlated with defect dimensions or the causes that produce them.

The materials used in this work were AISI 304, AISI 321, AISI 316 L and 12Ch21N5G2STL (Gost). Compositions of these materials are given in table 1. Samples with dimensions 100x10x1.5mm were deformed by cold rolling, in 10% steps up to 80% reduction at room temperature. This results in an array of samples. These samples were checked after every step of cold reduction for Vickers hardness, eddy current signal strength, phase of eddy current and x-ray diffraction method has been used to determine for volume percentage of austenite determination. In order to enable X-RD of the specimens polished surface of the material were prepared. Eddy current equipment ***Defectomat 2.830*** operating at 4 KHz with sensitivity 10 db. Absolute surface probe was used for eddy current measurements that respond to all variables which effects eddy current flow [8-9]. The phase of lift off signal was rotated to be parallel to horizontal axis, which was about 180 degree. Low frequency was used because it provides a good impedance resolution. The instrument was calibrated with a non rolled sample and rest of the samples were tested using this calibration.

Table 1. Chemical composition of stainless steel alloys (w %).

Alloy	Si	Ni	Mo	Mn	Ti	Cr	C	S	Fe
AISI 304	0.56	8.2	-		1.22	18.94	0.0547	0.00135	Bal
AISI 321	0.64	8.39	-	1.44	0.68	17.84	0.058	0.003	Bal
AISI 316L	0.33	11.43	2.28	1.64	-	17.79	0.01	0.0047	Bal
12Ch21N5G2STL(Gost)	0.61	6.41	-	0.57	0.55	22.31	0.058	0.0082	Bal

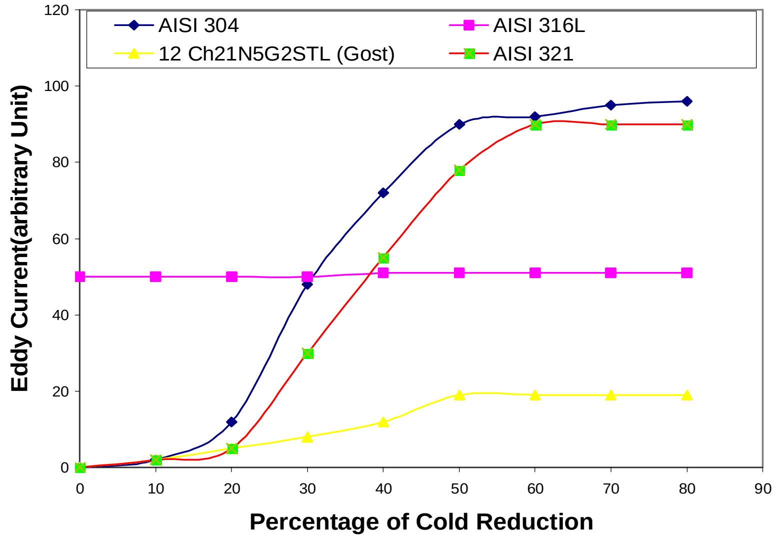

Fig 1-; Variation of eddy currents as a function of cold reductions.

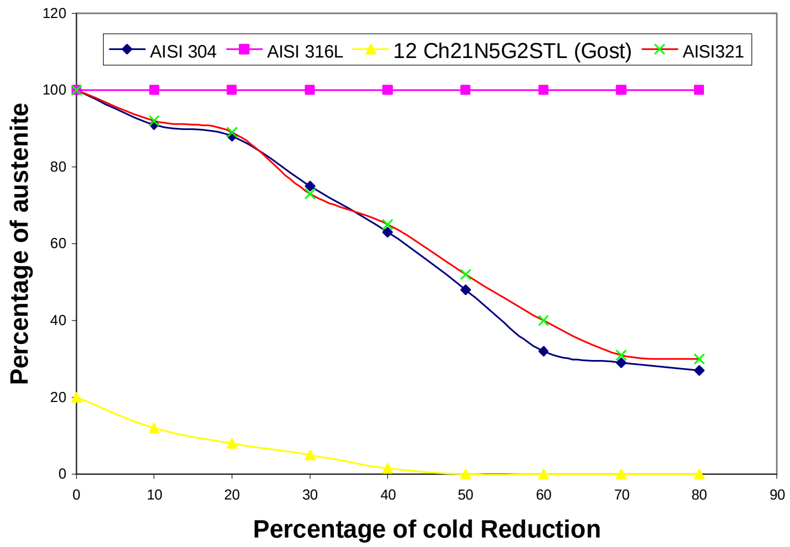

Fig 2-: Variation of austenite as a function of cold reductions.

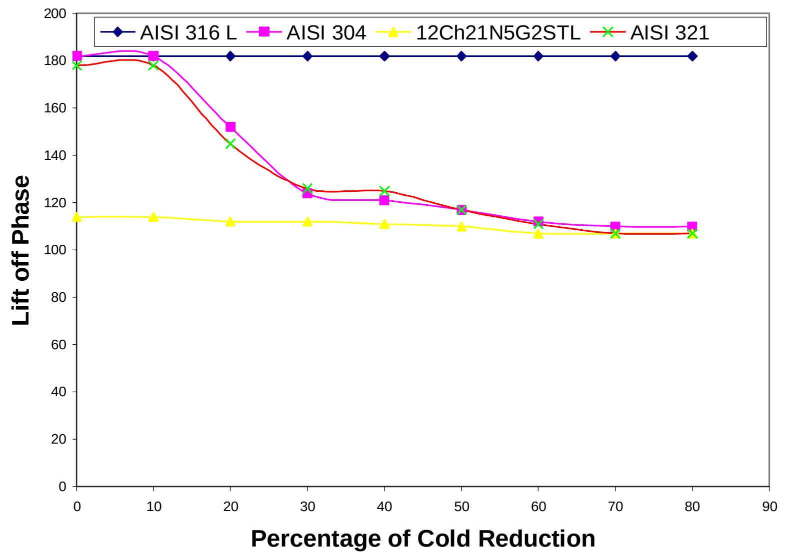

Fig 3-: Variation of lift off as a function of cold reductions.

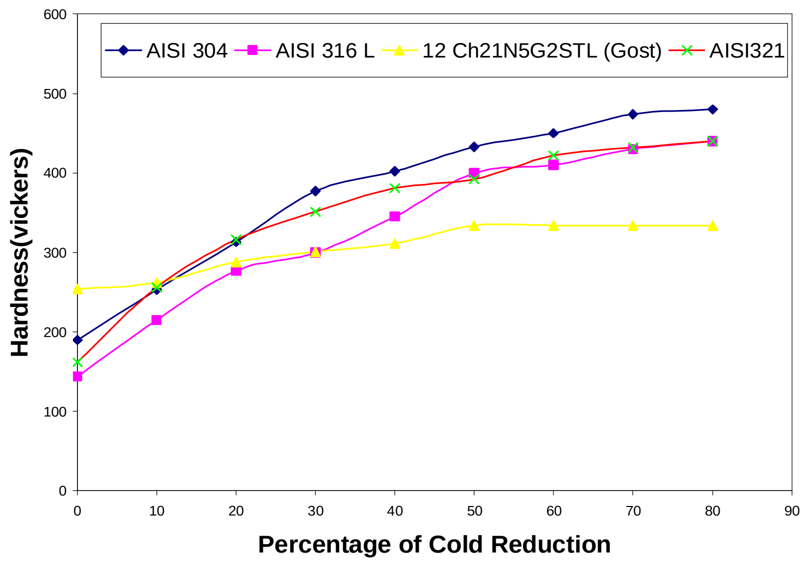

Fig 4-: Variation of hardness as a function of cold reductions.

3. Results and discussion:

The change of eddy currents as received condition of AISI 316L, AISI 304, AISI 321, and 12Ch21N5G2STL as a function of cold deformation is shown in Fig 1.The results in AISI 316L the eddy current values are independent of cold deformation. This means that there is no affect of eddy current impedance on grain size, residual stress, hardness, tensile strength and dislocation densities, although these parameters are affected with the cold reduction whereas in AISI 304 L and AISI 321 eddy current values moves up to 15% then it increases sharply up to 50 percent. It behaves differently after 50 percent. It becomes insensitive because austenite does not vary in that portion of cold reduction and in 12Ch21N5G2STL it behaves like AISI304 and AISI 321 with lesser sensitivity.

Compare now results measured by x-ray diffraction method for calculating percentage of austenite. After cold reduction in AISI 316L, AISI 304, AISI 321 and 12Ch21N5G2STL Fig 2 shows that in AISI 316L like eddy current values there is no austenite variation. In AISI 304, AISI 321 and 12Ch21N5G2STL austenite decreases slowly up to 15 percent of cold reduction then it decreases sharply and stays constant after 50 percent of reduction. This confirms our hypothesis that austenite is responsible for changing eddy current values.

Fig. 3 shows that lift off phase is also sensitive to cold reduction. In AISI 316L its influence to cold reductions seems to be negligible. Whereas in AISI 304 and AISI 321 it first decreases slowly then sharply (approx.) up to 50 percent and finally it stays constant. In 12Ch21N5GSTL (Gost) it decreases very slightly before it stays constant like austenite variations.

Fig. 4 represents Vickers Hardness in strained samples which increase with the increase in amount of cold rolling up to 40 percent then it begins to saturate in three stainless steel samples. This would suggest increase in hardness which may be due to the movement of dislocations in the presence of obstacles that leads to the strengthening of material. Comparatively less hardness from 40 to 80 percent could be a consequence of a phenomenon called “work softening”. In his papers Mullner [10-12] discusses this phenomenon and explains it in terms of dislocation reaction at twin boundaries.

4. Conclusion

This study shows that out of the three properties studied only austenite variation affects the eddy currents and its lift-off phase in all the samples. Keeping in view our finding in [5&6] it can be inferred that eddy current values can be used during rolling of stainless steels for calculating their percentage of austenite.

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