TEXTURE AND CHARACTERIZATION OF MECHANICAL PROPERTIES IN PURE NICKEL

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Abstract

Anisotropy as a consequence of cold rolling modes and cold rolling reduction always correlates crystallographic texture which plays an important role on deformation and mechanical behavior of materials. Textures develop in metallic materials as a result of almost all metal working operations. Since many applications require metallic material in sheet or plate form, evolution of textures resulting from rolling of these is worth studying. The present study is aimed at examining the effect of modes and extent of rolling on yield surface anisotropy, microstructure and texture of the pure nickel. Hot rolled sheets of pure nickel of thickness 7 mm were subjected to different reductions using various modes of rolling, namely, unidirectional, two step cross-rolling and multi-step cross rolling. As consequences of different rolling modes and various percentage reductions the yield surfaces which changed were correlated with texture.Cold rolling of the starting material leads to marked increase in size of yield surface and this trend increases with increase in the degree of reduction, As a consequence of rolling reduction the shape and size of yield locus plots changes. As the rolling reduction increases from 30 to 85% in unidirectional, two steps and multi-step rolling modes the area of the yield locus plot (area of ellipse) increases for pure nickel, which indicates texture hardening. Both hot rolled and cold rolled pure nickel (unidirectional, two steps and multi-step rolling modes) shows mechanical property anisotropy and a definite nonrandom texture at 85% reduction.

Keywords: Anisotropy, Deformation, Rolling, Texture, Yield locus

I. INTRODUCTION

It is known that any metal in its purest form has higher stacking fault energy (SFE) than their alloy forms, which indicates higher and easy deformation characteristics of pure metals with respect to their alloy forms. It is also proven that nickel base alloys show mechanical property anisotropy after cold working. The anisotropy can further be altered by different mode of cold rolling and varying percentage cold reduction. The core reason behind the anisotropy lies on the ability of the metals and alloys to exhibit different degree of crystallographic orientation capability after various modes and percentage of cold rolling. For engineering structural application anisotropy of metals and alloys are undesirable whereas for electrical and magnetic application it is desirable, that leads us to understand the basic idea of anisotropy and its correlation with texture. The conventional cold rolling process is unidirectional rolling using two or four high mills. But it was shown that with various other modes of rolling such as clock rolling, two steps cross rolling, multi-step cross rolling, reverse rolling, warm rolling etc., mechanical, electrical and magnetic properties of metals/alloys can be altered up to considerable extent. Mechanical, magnetic, and electronic properties can all vary widely as a function of crystallographic direction in a single crystal. In polycrystalline materials, this directionality of properties can be a consequence of crystallite or cell-shape anisotropy, particle morphology, or preferred orientation. In the present discussion, texture refers only to preferred orientation of the crystallite lattice, or crystallographic texture. This is only achieved through strategic processing of the rolled sheet [1-5]. It must not be assumed, however, that preferred orientation is invariably undesirable. The use of strongly textured steel sheets for the cores of power transformers is well known. To study the effect of various modes of cold rolling and percentage reductions on deformability characteristics and mechanical property anisotropy (particularly tensile strength, micro hardness and yield locus) of as received hot rolled pure nickel metals. Finally to study the texture-property correlation as a function of various modes and percentage reductions of cold rolling.

II. EXPERIMENTAL WORK

A. Tensile Test

The tensile specimens were cut from the as received hot rolled sheets of pure nickel in three different directions namely, longitudinal (L or 0º), 45º (specimen axis at 45º to the rolling direction) and transverse (T or 90º) directions. The longitudinal direction corresponds to the rolling direction (RD) and transverse direction (TD) is the direction perpendicular to the rolling direction. These tests were conducted at room temperature at a normal strain rate (10^{-3} s^{-1}) on a screw driven Instron 1185 testing machine.

B. Cold Rolling

Each sample was cold rolled in three different modes of rolling by giving 30, 50 and 85 percentage of reductions. Three different modes of cold rolling followed were unidirectional cold rolling, two steps cross cold rolling and multi-step cross cold rolling. Each cold rolled samples in particular rolling mode and for a particular percentage of reduction and for a specific metal were given an unique identification as follows,

CRNU30 ~ Cold Rolled Nickel Unidirectional 30 percent reduction,

CRNT30 ~ Cold Rolled Nickel Two steps 30 percent reduction,

CRNM30 ~ Cold Rolled Nickel Multi step 30 percent reduction

similarly other samples were given identification as CRNU50, CRNU85, CRNT50, CRNT85, CRNM50 and CRNM85.

C. Texture Measurements

The texture measurements were carried out for as received hot rolled, as well as on sheet specimens after cold rolling in different modes and varying percentage reduction. The specimen size was having the area of 25 mm by 20 mm and all texture measurements were carried out at 1/4 thickness level from the surface. An inel G3000 texture goniometer coupled with curved position sensitive detector (PSD) using CuK_{α} was employed for texture measurements in Schultz back reflection technique [Schultz,1949].

D. Yield Locus Plots

The yield surfaces of the materials were determined by Knoop hardness method used by Lee et al. [6], based on Wheeler and Ireland approach [7]. A MMT-X7 model, Matsuzawa Co. Ltd. Knoop hardness tester with 500 g load was used to obtain KHN values. The 30 %, 50 % and 85 % cold rolled and polished specimens were indented for 20 s at 500 g load by Knoop indenter. The length of the long diagonal was only measured in each case for the calculation of KHN values. The yield strengths for different orientations a, b, c, d, e and f were calculated based on the formulation of Lee et al. [6].

III. RESULTS AND DISCUSSION

Tensile test was performed in three directions [0° with respect to the rolling direction (Longitudinal or L), 45° to the rolling direction (45°) and 90° to the rolling direction (Transverse or T)]. From the tensile test values given in Table 1 it can be seen that the yield stress and ultimate tensile stress are highest for specimens with 45° orientation and lowest for longitudinal specimens. This indicates that the as received pure nickel have some degree of anisotropy after hot rolling.

The degree of anisotropy after hot rolling was quantified with two parameters, In-plane anisotropy (A_{IP}) and Anisotropy index (δ), for hot rolled pure nickel. The calculations as per formula described used as follows,

$$A_{IP} = [2*YS (45°) – YS (T) – YS (L)] X 100 / 2*YS (45°) \quad [1]$$

$$\delta = [\% El (45°) - \% El (T)] X100 / [\% El (45°) + \% El (T)] \quad [2]$$

The values obtained were 12.6712 In-plane anisotropy (A_{IP}) and 2.6087in Anisotropy index (δ)

The yield surfaces of the materials were determined by Knoop hardness method used by Lee et al. [6] based on Wheeler and Ireland approach [7]. The average microhardness (KHN) of pure iron in each ND, TD and RD planes for different modes of rolling (Unidirectional, two steps and multi-step) and percentage reductions (30 %, 50 % and 85 %) are reported in Table 2. The range of micro hardness for pure nickel is from 181 to 276 KHN as given in Table 2.

The microhardness of TD plane of 30% cold rolled pure nickel is higher than the ND and RD planes for all the three modes of rolling. But for the case of 50% reduction hardness of RD plane is relatively more than TD and ND planes. It can further be noticed that hardness of ND plane is always lowest of all planes for all the three experimental modes of rolling. With 85% of cold reduction it can be observed that hardness of RD plane is higher than TD plane and hardness of TD plane is more than ND plane for unidirectional and two steps rolling modes. However with multi step rolling and at 85% reduction the hardness of ND plane is higher than both TD and RD planes.

Figures 1 – 3 shows the yield locus plots of pure nickel for all the three experimental rolling modes with 30% and 85% reduction. It can be seen that as the rolling reduction increases from 30% to 85% the area of ellipse increases for all the three modes of rolling which indicates pure nickel has a tendency to show preferred orientation of grains (texture) with increase in percentage cold reduction. The increase in area (considering RMSE values) of ellipse or texture hardening from 30% to 85% is more significant in case of multi-step and two steps rolling as compared to unidirectional rolling. Figure 4 shows the texture of 85%of unidirectional, two steps and multi-step cold rolled pure nickel has higher (111) pole figure intensity as compared to hot rolled sheets. It can be seen that maximum cold rolled intensity of (111) pole figure is 4.1 times random for unidirectional mode.

The texture hardening as observed above can be due to the rotation of crystallographic planes during cross rolling whereas the texture hardening during unidirectional rolling may be due to the orientation of planes in the direction of excessive slip.

IV. CONCLUSIONS

The present study revealed that the in-plane anisotropy (A_{IP}) in respect to tensile property in the hot rolled pure nickel is higher degree of anisotropy. The grains of cold rolled pure nickel do not show any significant elongation in ND and TD planes after 30 and 50% reduction in all the three experimental modes of rolling such as unidirectional, two steps and multi-step. But after giving cold reduction of 85%, the grains of RD planes elongated almost parallel to rolling direction in all the above rolling modes and this elongation is significant in case of unidirectional rolling as compared to two steps and multi-step rolling. Some of the flow lines are parallel to RD plane while some are quite away from it for all the rolling modes. At 30% cold reduction, TD planes have maximum microhardness values in all the modes of rolling. As the percentage reduction increases the RD planes exhibits maximum hardness value except in the case of 85% multi step cross rolling where it has minimum value of all the planes (here ND plane has highest hardness value). Cold rolling induces anisotropy in yield strength. As a consequence of this shape and size of yield locus plots changes. As the rolling reduction increases from 30 to 85% in unidirectional, two steps and multi-step rolling modes the area of the yield locus plot (area of ellipse) increases, which indicates texture hardening. Highest intensity of X-ray texture corresponds to the largest area of yield locus plot. The relatively highest intensity of texture features and the corresponding smallest area of yield locus in 85% unidirectional rolling as compared to 85% two steps and multi-step rolling contradict the above statement. The reason for this may be due to the evolution of (111) fiber texture while rolling in unidirectional mode with 85% reduction.

Table 1. Tensile test values of as received hot rolled sheets of pure nickel in different orientations.

Orientation of nickel (HR w.r.to longitudinalrolling direction.	0.2% Proof Stress (Yield Stress) in MPa	Ultimate Tensile Stress in MPa	% elongation on gauge length of 15 mm
Longitudinal (0°)	126	369	58
Transverse (90°)	129	375	56
45°	146	387	59

Table 2. Microhardness of pure nickel in ND, TD and RD planes for different modes of rolling and percentage reductions

CRNU30	Orientation	KHN	CRNT30	Orientation	KHN	CRNM30	Orientation	KHN
	ND (a)	188		ND (a)	190		ND (a)	188
	ND (b)	184		ND (b)	199		ND (b)	181
	TD (c)	210		TD (c)	194		TD (c)	190
	TD (d)	200		TD (d)	210		TD (d)	194
	RD (e)	207		RD (e)	193		RD (e)	192
	RD (f)	199		RD (f)	194		RD (f)	187
CRNU50	Orientation	KHN	CRNT50	Orientation	KHN	CRNM50	Orientation	KHN
	ND (a)	201		ND (a)	205		ND (a)	199
	ND (b)	235		ND (b)	202		ND (b)	187
	TD (c)	210		TD (c)	211		TD (c)	208
	TD (d)	233		TD (d)	212		TD (d)	184
	RD (e)	227		RD (e)	226		RD (e)	203
	RD (f)	217		RD (f)	213		RD (f)	223
CRNU85	Orientation	KHN	CRNT85	Orientation	KHN	CRNM85	Orientation	KHN
	ND (a)	223		ND (a)	246		ND (a)	260
	ND (b)	244		ND (b)	228		ND (b)	251
	TD (c)	236		TD (c)	245		TD (c)	255
	TD (d)	238		TD (d)	259		TD (d)	248
	RD (e)	262		RD (e)	255		RD (e)	233
	RD (f)	239		RD (f)	276		RD (f)	253

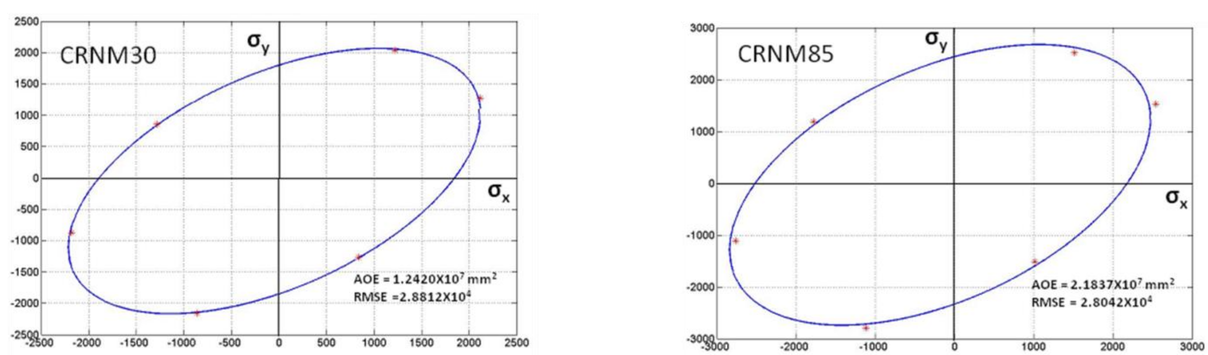

Fig. 1. Yield locus plots of the multi step cold rolled pure nickel in 30 and 85% reduction condition.

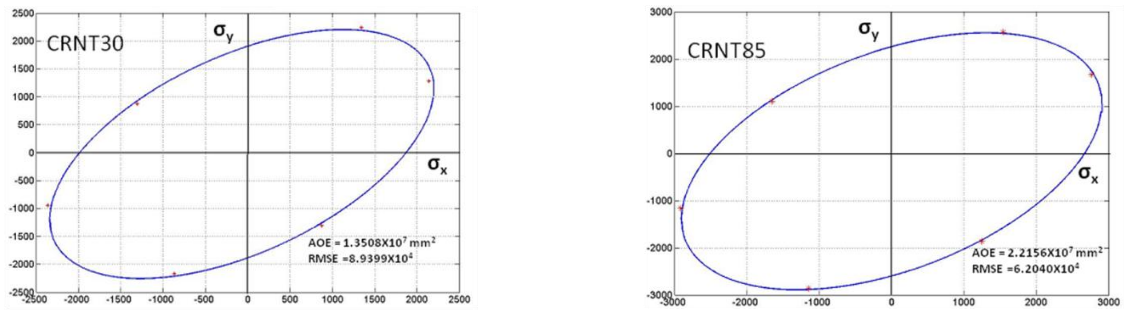

Fig. 2. Yield locus plots of the two steps cold rolled pure nickel in 30 and 85% reduction condition.

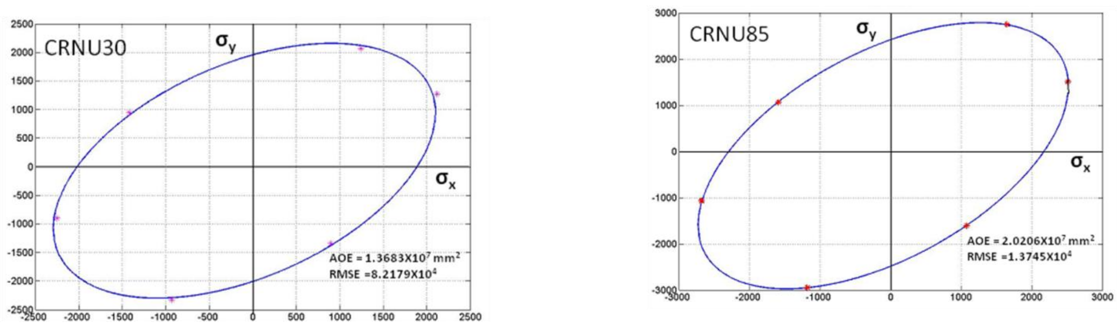

Fig. 3. Yield locus plots of the unidirectional cold rolled pure nickel in 30 and 85% reduction condition.

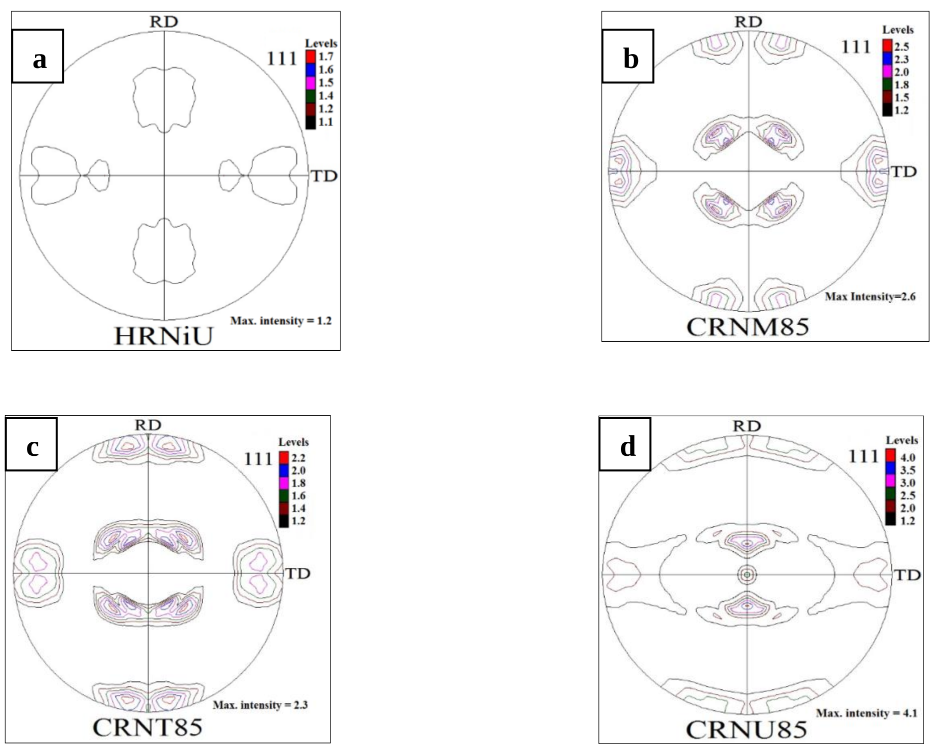

Fig. 4. Pole figures of (111) planes of (a) hot rolled, (b) multi-step cold rolled, (c) two steps cold rolled, and (d) unidirectional cold rolled pure nickel with 85% reduction.

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