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Engineering low intensity planar textures in commercial purity nickel sheets by cross roll bonding

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ABSTRACT

Accumulative roll bonding is a severe plastic deformation technique capable of generating nano-scale microstructures in sheet metals. This technique can also be exploited for processing novel sheet products that are not possible through conventional rolling. In this investigation, cross rolling was combined with accumulative roll bonding of commercial purity nickel sheets, for obtaining an overall reduction in intensity of the deformation and recrystallization textures, which has been a long-time objective for obtaining drawable face centred cubic metal sheet. Overall, a significant reduction in the texture intensities were achieved by incorporating cross roll bonding. In particular, the dominance of the cube texture component, which readily forms in heavily cold rolled and annealed high stacking fault energy, face centred cubic metals and alloys, was suppressed by adopting this processing route. Texture-based Schmidt factor calculations points to a significant reduction in planar anisotropy of the cross rolled and annealed sheet, which is an important factor governing the earing propensity of deep drawn cups.

1. Introduction

Sheet metals with a face centred cubic (fcc) crystal structure, such as Al-, Cu- and Ni-alloys etc., are intrinsically difficult to plastically deform into complex-shaped components, which is a major manufacturing process for creating formed components in the automotive, aerospace, food and beverage container industries. One of the principal reasons for the poor formability of fcc metals is the unfavourable crystallographic orientations of the grain aggregates (i.e. the crystallographic texture) that naturally forms in these materials during the rolling and annealing stages [1], which results in uneven material flow around the peripheral directions in the plane of the sheet during deep drawing. This phenomenon is also described by a geometrical parameter termed *planar anisotropy* (Δr), which is determined largely by the final crystallographic texture of the sheet. This parameter should be as close to zero as possible (Δr~0) for obtaining uniform flow in the plane of the sheet during deep drawing. However, to date, a large Δr-value is a generic limitation of fcc sheet metals processed by conventional rolling and annealing.

To address this planar anisotropy problem, there are two broad approaches. A crystallographic texture must be generated that is either: (i) uniform around the normal direction (ND) of the sheet, or (ii) random. Both approaches aim to minimize the preferential plastic flow in particular directions in the plane of the sheet. Extensive research has been conducted over many years to address this problem but success is limited to some more exotic processing routes such as twin roll casting and concurrent deformation [2]. It is pertinent to note that a balanced planar texture (Δr~0) is achievable in auto grade body centred cubic (bcc) alloys, but not in Al alloys; this is one of the reasons for hindering the wide-spread use of Al alloys as automobile panels. In the latter approach, an overall reduction in the texture intensity has been demonstrated through a process called cross rolling. Here, the rolling direction (RD) and transverse direction (TD) is rotated after each rolling cycle [3–7]. Hence, the texture that develops during a given rolling pass is disrupted in the next pass due to the change in stress coordinates associated with rolling; the overall result is a reduction in texture intensity. It has also been demonstrated that modification to the standard rolling/annealing schedule makes this approach more effective, such as incorporating intermediate annealing between certain rolling passes to allow minor thermal restoration of the deformation microstructure [8,9] and adopting higher strain rates during hot rolling to encourage extensive shear banding [10]. The latter technique as been applied to a number of commercial and laboratory fabricated alloys, including bcc steel [11], aluminium [12], nickel [13], and molybdenum [14]. While the outcomes are promising, industrial implementation is yet to be realized because of some technical

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challenges associated with the difficulties with long sheet formation in the rolling direction during the conventional rolling and coiling process.

In this investigation, cross rolling has been combined with accumulative roll bonding (ARB) of commercial purity fcc nickel for modifying the final annealing texture of the sheet. This technique can be used for processing any type of fcc alloy. Briefly on ARB, two metal sheets are cleaned, stacked and roll bonded by 50% rolling reduction in thickness. The bonded sheet is then cut into two for the next roll bonding cycle; this process continues for as many cycles as required. The final sheet contains numerous thin layers containing an internal nanostructure. Originally, this method was developed for processing nanostructured sheet metals with ultra-high strength and other desirable properties [15,16]. The aim of the current ARB process, involving alternating the RD and TD of the sheets between successive cycles, is to engineer a final sheet texture for improving the uniformity of plastic flow in the plane of the processed sheet, i.e. reducing planar anisotropy.

2. Experimental

Commercial purity Ni (99.8 wt%) sheets of ~1 mm thickness were cut into 50×50 mm rectangular samples. The initial structure of the sheet consisted of equiaxed, recrystallized grains of average diameter 30 ± 10 μm. The sheets were surface cleaned, stacked together and subsequently processed by both conventional roll bonding (hereafter termed ARB) and cross roll bonding (hereafter termed C-ARB) to six cycles using a laboratory rolling mill with 210 mm diameter rolls. Rolling was carried out without lubrication at 8 m/min at room temperature. During cross roll bonding, the sheets were rotated 90° about ND after each rolling cycle (i.e. the new RD is the previous TD). No intermediate annealing was conducted between the roll bonding cycles. After six ARB cycles, both processed sheets were annealed for 60 min at 650 °C in a muffle furnace to full recrystallization.

The evolution of the microstructure and texture during processing were studied mainly by electron backscatter diffraction (EBSD) using an Oxford *HKL* system attached in a CarlZiess Auriga field emission gun scanning electron microscope (FEG SEM). Samples suitable for EBSD were prepared by mechanical polishing to 0.04 μm using colloidal silica for the final polishing stage. EBSD scans were conducted in the ND-RD section for the ARB sample. For the C-ARB sample, the section containing the final RD and ND was examined. Depending on the structural resolution required, EBSD scanning ranged from 45 nm to 400 nm step sizes. For obtaining the overall texture of a given sample, several regions were scanned and the data combined.

3. Results and discussion

EBSD maps of the six-cycle roll bonded and annealed samples are given in Fig. 1a-d, whereby high (≥15°; HAGBs) and low angle grain boundaries (2–15°; LAGBs) are shown by the black and while lines, respectively. After deformation (Fig. 1a and b) the HAGBs are alligned parallel with the RD and RD_1, with the subscript in the latter denoting the cross rolling direction, i.e. RD_1 was TD in the previous cycle. A point-to-point misorientation plot generated an average HAGB spacing of ~80 nm. These thin bands, termed lamellar bands, are distinctive structural features of heavily rolled metals [17–19]. In the ARB sample (Fig. 1a), these lamellar bands appear wavy because of shear banding, but this waviness is not as prevalent in the C-ARB sample (Fig. 1b). This is because the current RD-ND section was the TD-ND section in the previous cycle, in which shear bands are less evident due to the geometry of the structures. After annealing for 60 min at 650 °C, the heavily deformed structures recrystallize to an equiaxed grain size of 12 and 10 μm in the ARB and C-ARB samples, respectively. Internal twins are also evident in many of the recrystallized grains in both materials.

The crystallographic textures of the deformed and recrystallized ARB and C-ARB samples were generated by EBSD (Fig. 2), with the data presented as standard ϕ2 ODF sections. Fig. 2a shows the textures of the ARB sample, whereby the principal fcc texture components, Copper ({112} < 111 >), S ({123} < 634 >) and Brass ({011} < 211 >), are labelled. These components, falling on the well-known β-fibre that develops in fcc metals after > 60% rolling reduction, are high in intensity (up to 27× random). In contrast, the highest texture intensity in the C-ARB sample is 9× random (Fig. 2b), and a few other low intensity orientations (~3× random) outside the β-fibre are evident. Hence, cross rolling clearly supresses the intensification of the β-fibre texture by changing the strain path and activating different slip systems in the process. A comparison of the Brass, S and Copper texture components in the ARB and C-ARB samples shows a significant reduction in texture intensity only for the S and Copper components (see Table 1), thereby indicating that Brass is a more stable component despite the change in strain path associated with C-ARB. This finding is supported by Huh *et al.* [20] who showed, for an Al alloy, that the Brass and {011} < 111 > components remain stable with a change in coordinates between RD and ND. After rolling, the volume fraction of the {100} < 001 > (Cube texture) component is very low in both samples. However, after annealing for 60 min at 650 °C, Cube is the principal texture component in the ARB sample with an intensity of 26× random but is weak in the C-ARB sample, with an intensity of less than 1× random.

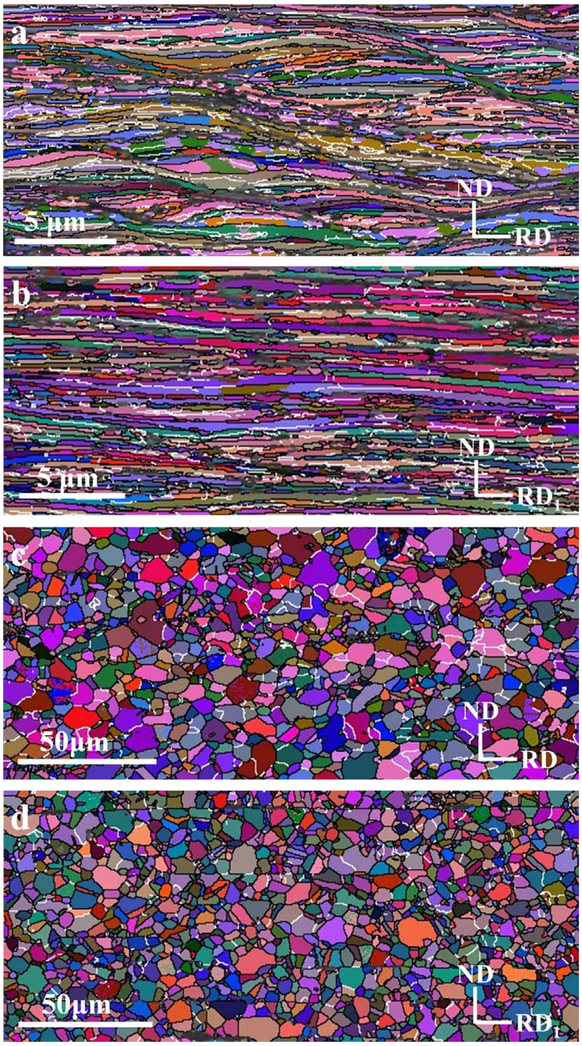

Fig. 1. EBSD maps showing the HAGBs (black lines) and LAGBs (while lines) in the deformation structures of samples produced by (a) conventional ARB (ARB) and (b) cross-roll ARB (C-ARB). The recrystallized microstructures of (c) ARB and (d) C-ARB samples following annealing for 60 min at 650 °C.