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Architectured duplex stainless steels micro-composite: Elaboration and microstructure characterization

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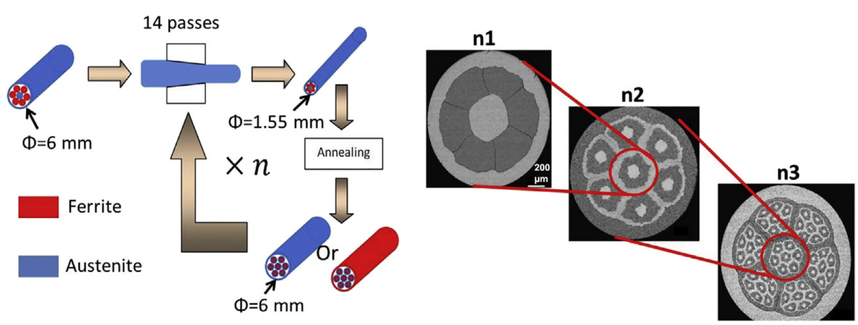
HIGHLIGHTS

- For the first time a composite dual phase stainless steel has been produced by accumulative drawing and bundling.
- The process enables to fabricate a dual phase microstructure while choosing the compositions of austenite and ferrite.
- The process limitation occurs when inter-diffusion during annealing heat treatments provokes austenite reversion.

GRAPHICAL ABSTRACT



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ABSTRACT

In this work we propose a *top-down* strategy in which an austenitic stainless steel (type AISI 316L) and a ferritic stainless steel (type AISI 430LNb) are mechanically alloyed by Severe Plastic Deformation (SPD) to elaborate an architectured duplex stainless steel. This proposed strategy serves two main objectives: i) enhancing the properties by microstructure refinement down to sub-micron scale, and ii) elaborating a model material for understanding the behavior of Duplex Stainless Steel (DSS) obtained by the conventional metallurgical methods. The Accumulative Drawing and re-Bundling (ADB) technique has been successfully implemented for these specific materials, allowing to obtain multi-scale micro-composites of 316L/430LNb steels. The limits of this process in terms of microstructure refinement, have been identified as due to the complete regression of the micro-scale austenitic phase during annealing.

1. Introduction

Combining two or more different materials in the view of obtaining a material with better properties than those of the individual components used separately is the basic concept of composite materials. In the late 1960s, a new class of metal-metal composite materials was developed, in which both matrix and the dispersed component can be co-deformed plastically. Fe-Fe_3C composites obtained by Embury and Fischer [1] showed a Hall-Petch type increase of strength with decreasing microstructure scale and their ultimate tensile strength reached 4.8 GPa. Although some authors do not classify Fe-Fe_3C as a deformation processed metal-metal composite (DMMC) because of the limited plasticity of Fe_3C, it has been considered as a precursor material for the development of DMMCs in various applications [2]. Depending on their manufacturing routes, these composites are obtained either by co-melting two metals that are miscible as liquids but immiscible as solids followed by large section reduction using Severe Plastic Deformation (SPD) techniques to obtain filamentary structure called in-situ *composites* [2]; or by assembling mechanically the constitutive metallic

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Table 1
Nominal composition (in wt%) of the stainless steels used in the present work.

Grade	C	Cr	Ni	Mo	Mn	N	Nb	Si
430LNb	0.014	18.05	0.2	0.039	0.382	0.016	0.490	0.398
316L	0.019	16.73	11.10	2.034	0.795	0.029	0.028	0.505

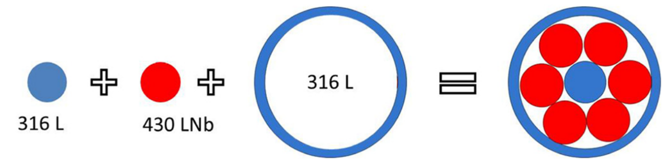

Fig. 2. Configuration of the first composite.

components by SPD resulting in so-called *co-deformed composites* (*or continuous composites*) [3]. Among the latter category, there has been in particular a large interest for the accumulative roll bonding (ARB) process which has been applied to generate a large number of different composite systems, such as Al based [4–14], Mg-based [15,16], Cu-based [17–22], Zr based [23], or Fe-based [24–29]. On the other hand, the interest in the accumulative drawing and bundling process (ADB) composites is to produce micro- or nano-structured wires. Cu-based composite wires have particularly been investigated in the aim to combine electrical conductivity and strength. The first deformation processed Cu-Nb in-situ composite obtained by [30] showed indeed an excellent combination of high strength-electrical conductivity. Following these results, several authors investigated Cu based composite with other metals such as Ag [30], Fe [31], Ta [32], V or Cr [33]. However, Cu-Nb is still considered as one of the most successful systems of mechanically alloyed composites using SPD techniques in terms of resulting properties and the comprehension of the deformation mechanisms. Nanocomposite wires of Cu-Nb obtained directly from the ADB process resulting in continuous fibers with controlled distribution of Cu and Nb, show interesting mechanical and electrical resistivity. Such nanocomposites have been investigated by [34–40]. Composites using other metals than Cu have been also explored e.g. for microelectronic applications such as Au-Ag [41] or more recently Al-Ca [42]. Metal-Metal composites are also of interest for structural applications. For example, the systematic investigations realized on Al-Mg [43], Al-Sn [44] and Al-Ti [45] showed an ultimate tensile strength significantly higher than that of pure Al.

Duplex Stainless Steels (DSS), with a microstructure consisting of approximately equal volume fractions of austenite and ferrite, have been recognized as interesting dual phase alloys for structural applications since the 1970s. DSS can be obtained by solidifying a specific chemical composition having a nickel content between 4 and 7%, and a chromium content of 18–25% [46]. They show good combinations of strength and ductility, such as a ultimate strength above 1GPa and a ductility of almost 25% for in-situ DSS composites designed recently

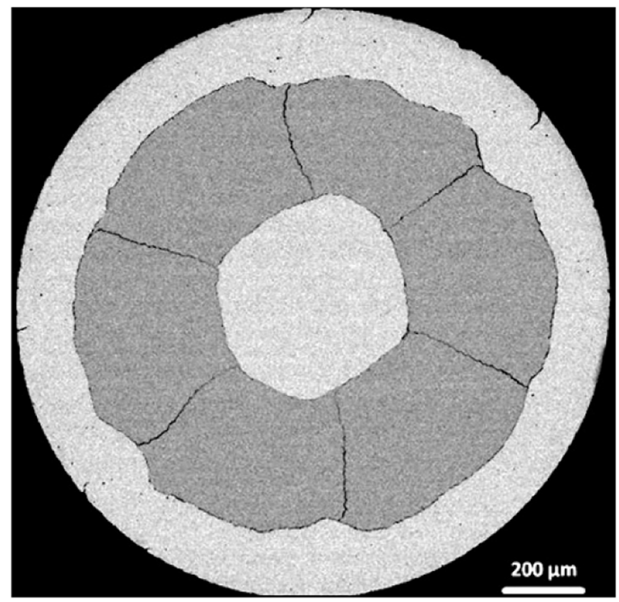

Fig. 3. SEM image in BSE mode of the microstructure of n1 composite in the as-drawn state (Ferrite: dark grey, Austenite: light grey).

[47,48], coupled with very interesting functional properties such as corrosion resistance and comparatively lower thermal conductivity.

However, the mechanical properties of DSS are still the subject of many research investigations aiming at understanding their strength/ductility compromise and at rationalizing microstructure/mechanical properties relationships. In [49] it has been proposed that the mechanical properties of DSS result from a complex interaction between ferrite and austenite leading to a mechanical behavior that cannot be predicted from the properties of the constituents alone, claiming that the strength

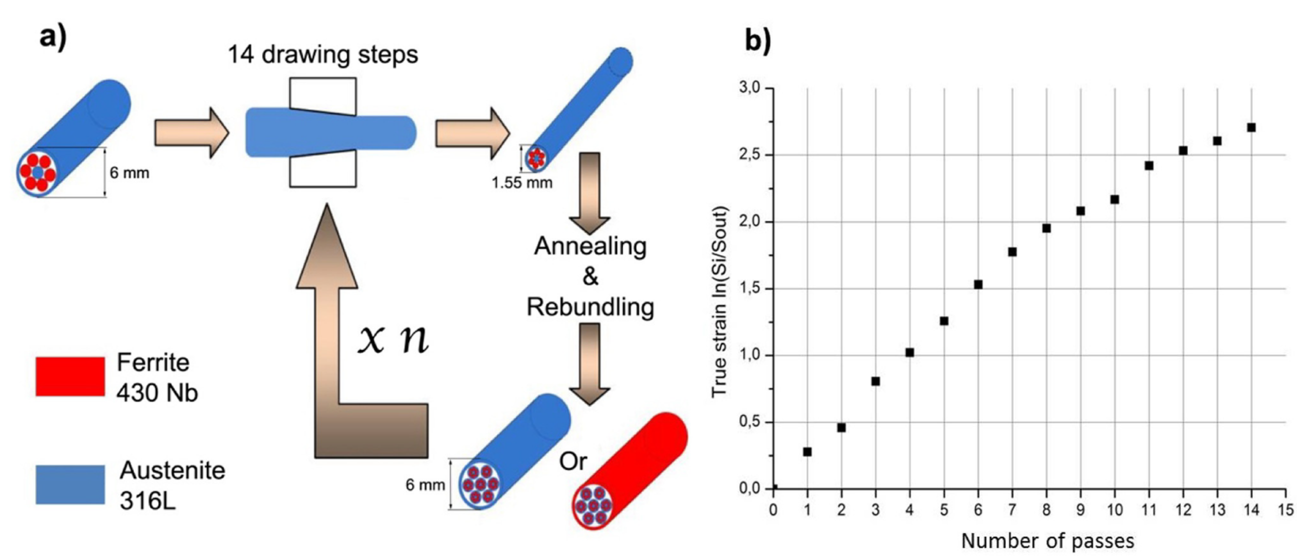

Fig. 1. a) Schematic illustration of the ADB process b) Evolution of the true deformation during drawing as a function of the step number where S_i is the global input section and S_{out} is the global output section.