General Introduction

Since the 1950s, the use of automobiles increased continuously all over the world, making of gas effluents one of the major concerns for all modern societies. From the economic and ecological points of view, everyone agrees on the fact that the consumption of fossil fuels for transport must decrease. One of the approaches to diminish the fuel needs of a vehicle is to reduce its mass. Different designs and alloys have been used to lower the weight of the engine. Moreover, quite large improvements have been achieved for the weight of the car body, while keeping the security of the passengers at the same level. The car body is thus thinner, and thereby lighter, provided that the appropriate metal is used. Indeed, this material must be ductile enough to keep a high formability but also strong enough and able to absorb the shock energy in case of crash. These requirements have to be fulfilled correctly if steel wants to keep its leading position in the automotive industry with respect to aluminium and composite materials.

Steel presents the advantage that a wide range of properties can be obtained thanks to the existence of numerous phases and phase transformations. A wide range of studies has shown that mechanically-induced phase transformations (TRIP effect) of the austenite may bring about excellent mechanical properties in steel grades [Bhan72, Olso78, Tamu92, Jacq98]. However, the maximum proportion of austenite at room temperature is small in low alloyed grades. On the opposite, highly alloyed steels can be designed to present very high levels of austenite which would be susceptible to transform. Once developed mostly for their corrosion properties, stainless steels are arousing more and more interest for their high structural performances. Austenitic stainless steels presenting mechanically-induced phase transformation seem thus to be very promising.

Stainless steel is the generic name for different steels used primarily for their corrosion resistance. It is generally accepted that stainless steels were discovered in Europe, somewhere in the early 20th century. They were referred as "stainless" after one had failed to stain them with vinegar. "Corrosion resisting" steel would be more appropriate, as ordinary stainless steels do finally suffer from corrosion in hostile environments. All stainless steels share a minimum percentage of 12% chromium, which is the key element for the corrosion resistance. Indeed, chromium present in stainless steels has a great affinity for oxygen and forms a thin film (about 130Å) of chromium oxide on the surface of the steel. This layer is described as passive (*i.e.* it does not react or influence other materials), adherent and self-renewing (if damaged, more chromium from the steel will be exposed to the air and will form more chromium oxide). Fully austenitic grades are generally obtained by additions of nickel. Adjusting the chemical composition allows to maximise the TRIP effect and the mechanical properties. However, the replacement of some alloying elements has been investigated in order to keep high mechanical performances at a lower cost. This leads to the development of other highly alloyed steel grades, more economical but presenting a lower corrosion resistance than Ni-Cr stainless steels.

Besides the chemical composition, the grain size is an important parameter dictating the mechanical properties. Modifying the grain size represents a cheap and quite easy way to adapt the mechanical properties. Indeed, grain size reduction enhances the resistance of metallic alloys. Moreover, the grain size also influences the mechanically-induced phase transformations. Therefore, controlling the grain size is of primary importance for this type of materials. To refine the grain size, the main challenge is thus to bring about large nucleation to obtain a large number of grains and limited grain growth to prevent some grains to grow at the expense of others.

Finally, in addition to the chemical composition and grain size, the mechanically-induced phase transformations are also sensitive to the deformation temperature and the stress state. Therefore, the influence of these factors, the phase transformations and the mechanical properties are capital to determine the forming parameters for an industrial use.

Objectives

The primary objectives of this thesis are to investigate the interactions between the phase transformations and the mechanical properties under various conditions of chemical composition, grain size, temperature or stress state. Indeed, the austenite is well-known to transform into both ε- and α'-martensite during straining [Good70, Bree71]. In different highly alloyed steel grades, these transformations have been reported to take place together or successively [Ven61, Tomo86, Jee01]. This work will be centered on how the transformations occur in the stainless steels 301LN and 304, as well as in two Fe-Mn-Si-Al steel grades with additions of aluminium and silicon. This study will be carried out at the macroscopic scale as well as at the scale of the individual grains. At a macroscopic scale, the influence of the chemical composition, strain rate, grain size and stress state on the phase transformations and mechanical properties will be investigated. At a grain scale, this work will focus on the details of the transformation steps, orientation relationships and variant selection, which are still not completely elucidated in highly alloyed steels.

In order to study the effects of these various parameters on the phase transformations, samples with different microstructures will have to be processed. The secondary objectives of this thesis are two-fold :

1) to find out the impact of the chemical composition and annealing conditions on the microstructure of Fe-Mn-Si-Al grades ;

2) to process stainless steels with various grain sizes and to study the efficiency of different techniques of grain refinement.

General Outline

Chapter I will remind briefly the main concepts necessary to understand the mechanically-induced phase transformations and their relationships with the mechanical properties. The influence of the chemical composition, temperature and grain size on the phase transformations will be described. Moreover, the action of phase transformations as deformation mechanisms and their interactions with the mechanical properties will be explained.

Chapter II will present the materials and the details of the experimental methods used in this thesis.

Chapter III will study the Fe-Mn-Si-Al steel grades, particularly their microstructures, local chemical compositions and grain sizes.

Chapter IV will focus on the changes of the grain size of the 301LN stainless steel. Two methods will be investigated : deformation – annealing cycles and transformation – annealing cycles.

Chapter V will present a thorough analysis of the phase transformations in the Fe-Mn-Si-Al and stainless steel grades. It will investigate the mechanisms of mechanically-induced transformations at the grain scale and try to understand precisely the relationships between the multiple phase transformations, the orientation relationships and the variant selection phenomena. Moreover, it will also examine the influence of the stress state on the phase transformations in stainless steel 301LN.

Finally, *Chapter VI* will study the phase transformations on a macroscopic scale and evaluate the influence of various test parameters (such as the chemical composition, the austenite grain size, the strain rate and the stress state). Moreover, the role of the different phases and of the phase transformations on the mechanical properties will be investigated.

References :

[Bhan72] D. Bhandarkar, V. F. Zackay and E. R. Parker, *Metall. Trans.*, 1972, Vol. 3, p. 2619.

[Bree71] J. F. Breedis and L. Kaufman, *Met. Trans.*, Vol. 2, 1971, p. 2359.

[Good70] D. Goodchild, W. T. Roberts and D. V. Wilson, *Acta Metal.*, 1970, Vol. 18, p. 1137.

[Jee01] K. K. Jee, J. O. Song, W. Y. Jang, M. C. Shin and C. S. Choi, *Journal de Physique IV*, 2001, Vol. 11, p. 211.

[Olso78] G. B. Olson and M. Azrin, *Met. Trans. A*, 1978, Vol. 9A, p. 713.

[Tamu92] I. Tamura and C. M. Wayman, *Martensitic transformations and mechanical effects* in *Martensite*, 1992, edited by G. B. Olson and W. S. Owen for ASM, p. 227.

[Tomo86] Y. Tomota, M. Strum and J. W. Morris Jr., *Met. Trans. A*, 1986, Vol. 17A, p. 537.

[Vena62] J. A. Venables, *Philosophical Magazine*, 1962, Vol. 7, No. 8, p. 35.