Abstract

This thesis deals with understanding the deformation of automotive grade sheet steels at various strain rates, ranging from 0.001 to 800 /s. The purpose of selecting such high strain rates (> 1 /s) is to assess the dynamic deformation behaviour of these materials when they are subjected to impact like situations as it happens during 'crash' events, where the local strain rate can exceed 100 /s. It is also well known that metallic materials possess rate dependent properties and it is imperative to say that the material properties at such dynamic conditions will be different from those at nominal strain rates. Crashworthiness assessment of the automotive components thus need the dynamic properties of materials.

In this regard, four different commercially available automobile grade sheet steels have been selected on the basis of their variation in the microstructure. Interstitial free (IFHS) steels with largely ferritic structure with a minor content of titanium carbo-nitrides, ferrite/martensite dual phase steels of two different martensite content (DP600 and DP800) and a ferrite/cementite carbon manganese (C-Mn-440) steel have been selected for this study. The selected steels are deformed in tensile at strain rates ranging from 0.001 to 800 /s. The test parameters for high strain rate tensile tests (100, 400 and 800 /s) were decided upon performing an exhaustive test standardization process employing only interstitial free steel grade. The test standardization exercise also investigates the influence of specimen geometry, dimension and operating cross-head velocity on the noise generation during high strain rate tests. The obtained stress-strain behaviour at various strain rates was analyzed to determine their properties at various strain rates. The strain rate sensitivity and strain hardening behaviour of these steels at various strain rates have been investigated from the tensile curves. It is found that the strain rate sensitivity increased at high strain rates but it decreased with plastic strain in the materials investigated. The individual strengthening mechanism of the materials also found to have an influence on the overall strain rate sensitivity of the material. Based on the nature of flow curves at various strain rates, suitable constitutive relations were examined to select a constitutive model to predict the flow behaviour at different strain rates.

The deformation behaviour of these materials at different strain rates have been further investigated by observing the microstructure of the deformed specimens under transmission electron microscopy as well as through orientation image microscopy. Dislocation-dislocation interaction was prevalent in interstitial free steel and the rearrangements of dislocations intensified at high strain rates to produce a higher recovered microstructure. The sub-structural features possessed a contrasting difference at low and high strain rates which could explain the nature of plastic deformation in the materials at different strain rates. The interaction of dislocation with microstructure was present in dual phase steels. With martensite content, the dual phase steels showed distinctly different behaviour at high strain rates. While dynamic recovery was prevalent in DP600 at high strain rates, in DP800 martensite fragmentation increased the work hardening in ferrite grains at high strain rates. Emphasis has been given to understand the effect of strain rate on the strain incompatibility between the two phases at various strain rates in the dual phase steels which further helped in understanding the failure mechanisms in these materials. The influence of precipitate in the ferrite matrix of the carbon manganese steel was found to be crucial in maintaining the strain hardening rates of the steel at various strain rates. The influence of strain rate and microstructure on the ductile fracture process is also evaluated for all the materials.

Keywords: High strain rate; automotive grade steels; deformation behaviour; ductile fracture; damage evolution; Constitutive relations.