Abstract

Abstract: 9Cr steels are extensively used as heat resistant applications because of the balanced mechanical properties and forming ability like casting, forging, rolling, and welding performance. A large importance has been given to the composition design by alloying addition, characterization of microstructure and performance of 9Cr steels in service condition. It is possible to improve the performance of 9Cr steels by selection of proper composition, processing parameters and heat treatment schedule that control the lath and pocket size, density, morphology and distribution of different precipitates like MC, and $M_{23}C_6$.

The present work has been carried out aiming to understand the effect of individual alloying elements like vanadium, niobium and titanium in microstructure and property of 9Cr steels. Three different 9Cr steels with fine distribution of nano-sized precipitates have been designed and produced with tailor made microstructures for high temperature applications. Three different alloying elements namely vanadium, niobium and titanium have been incorporated in the steel. The cast steel has been homogenized at 1200˚C and subsequently forged to a reduction of around 40% thickness. The forged material has been further tempered at 500-800˚C for various interval of time. A detailed characterization of the microstructure has been carried out for cast, forged, rolled and subsequent heat treated steel using Dilatomtery, Optical Microscopy, SEM, XRD. The precipitation behavior of carbide particle has been studied for vanadium, niobium and titanium modified steel. The precipitates have been characterized by SEM, TEM and EDS analysis. The mechanical and high temperature properties like bulk hardness, room and high temperature tensile properties, creep and cyclic oxidation behavior have been studied.

Initial cast and forged microstructure consists of martensite with varying amount of retained austenite. MC and $M_{23}C_6$ type precipitates are formed during tempering. Nano-sized MC type precipitates consist of vanadium, niobium or titanium depending on the steel composition. $M_{23}C_6$ type precipitates are mainly chromium rich carbides and are found in all verities of steel. The density, size distribution and morphology of the precipitates change with change in heat treatment temperature and time.

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The microstructures are correlated with mechanical properties like hardness, tensile test. Hardness decreases at higher tempering temperature and time due to tempering of martensite. A change of the room temperature tensile properties is observed with change in tempering temperature. Maximum tensile strength and ductility are observed at 700-750˚C temperature range for all the modified steels. High temperature tensile test results show a reduction in yield, ultimate tensile strength and an improvement in ductility. Tensile properties are best for niobium containing steel at 500 and 600°C temperature.

The creep behavior of the modified steels is also carried out at 600˚C with different load of 60, 90, and 120 MPa. The nature of the creep curve changes with load. The best creep properties are observed for niobium modified steel at 120 MPa. The coarsening of precipitates is observed during long term creep at 60 MPa load.

The cyclic oxidation test results indicate that the oxidation behavior is parabolic in nature at 600-700°C. The oxide scale consists of FeO, Fe_2O_3 and $(Fe,Cr)_3O_4$. Titanium modified steel exhibits best oxidation resistance due to low carbon content and presence of titanium.

Keywords: 9Cr steel, microstructure, tempering, precipitate, hardness, tensile property, creep, cyclic oxidation