Abstract

The mechanical and corrosion behaviour of three ex-service rail axles were studied and compared with the specifications of standard grades. The axle steels had lower hardnesses, lower yield and ultimate tensile strengths than the recommended standards, although three is a very small data set to arrive at these generalisations. The axle steels had ferrite-pearlite microstructure, with pearlite decreasing from the surface to core, thus decreasing hardness. Similar interlamellar spacings were obtained for the pearlite colonies and there were coarse Widmanstätten and allotriomorphic ferrite.

The potentiodynamic corrosion rates of the axle steels in natural rainwater and in Johannesburg Municipal tap water were similar and lower than in synthetic seawater. Similar trends were observed for the immersion tests and there was no discernible effect on the nature of rust, with increasing exposure time. The corrosion rates of the axle steels increased with increasing exposure time. The analysed rust phases were mainly lepidocrocite, iron residue, magnetite and goethite, whereas akaganeite was associated with steels in 3.5% NaCl solution. The corrosion rates of the axle steels in each medium were similar due to small amounts of Cr, Ni, Mo, Cu and Si, as these elements increase corrosion and oxidation resistance in medium carbon steels.

Thermo-Calc calculations were used to identify potential steels with lower cementite proportions to improve the corrosion resistance. Three steels from these were selected and produced, then tested, and two steels were identified for further tests, to ascertain whether they could be used as substitute for currently-used axle steels.

Thermo-Calc calculations of the standard grades were used as a baseline for the alloy design of the experimental steels, with varying amounts of Cr, Mo, Ni and V, ensuring improved mechanical and corrosion properties. Steels with lower cementite phase proportions and high corrosion indices were identified to improve the corrosion resistance and three selected compositions from the Thermo-Calc calculations were cast, heat treated and microstructures characterised. The air-cooled steels showed laths of bainite and ferrite. Banded ferrite-pearlite was obtained for the furnace-cooled steels, whereas mixed laths of bainite and martensite were observed for the quenched and tempered steels.

The corrosion rates of the as-rolled and water-quenched steels, and for the oil quenched and tempered steels, in tap water and in 3.5% NaCl solution were higher than the normalised, air and furnace-cooled steels. Although the ex-service rail axle steels showed better corrosion resistance than the as-rolled and water-quenched steels, as well as the oil quenched and tempered steels, they were poor compared to the normalised in air and furnace-cooled steels, due to bainite and ferrite of the normalised and air cooled, whereas a ferrite-pearlite and ferrite-bainite microstructure existed for the normalised and furnace-cooled steels.

The wear rates of the experimental steels were slightly lower than the ex-service axle steels, showing better wear resistance. The wear rates calculated using the maximum penetration depth and wear track width were slightly higher than those calculated using the Japanese Industrial Standard. The low wear rates of the experimental steels were due to high hardnesses from bainite and martensite microstructures. The main wear mechanisms were material pull-out, smearing and ploughing and the harder microstructure acted as the load-bearing phase.

The yield and UTS of the quenched and tempered steels were much higher (668 - 1158MPa, 880 - 1306MPa) than the air-cooled (455 - 587MPa, 767 - 880MPa) and the furnace-cooled (389 - 490MPa, 679 - 706MPa), which was the least, which was greater than that for the ex-service axles. The improved yield and UTS of the quenched and tempered steels were due to increased proportions of martensite and bainite. The normalised, air and furnace-cooled steels showed balanced strength, ductility and corrosion resistance required for rail axles.

The heat-treated experimental steels had better mechanical and corrosion properties than the ex-service axle steels, the proprietary and European Standard grades. However, the normalised, air and furnace-cooled SPA_18C and SPA_19C steels were the overall best steels due to their balance of strengths, hardness, ductility, toughness and good corrosion resistance than the other experimental steels, the ex-service axle steels, the proprietary and European Standards. It is also recommended that the rail axle steels with ferrite-bainite are used rather than the ferrite-pearlite steels, due to the balanced mechanical and corrosion properties of the former.