The Laves phase embrittlement of ferritic stainless steel AISI 441 used in shells of vehicle catalytic converters

by Maitse Sello and Prof Waldo Stumpf

Columbus Stainless of Middelburg is the primary manufacturer of flat wrought stainless steel products in southern Africa. One of the growth sectors in the use of stainless steel is in the automotive components industry and – more particularly – in catalytic converters for use in vehicles.

The manufacture of automobile emission control systems in South Africa is one of the fastest growing industry sectors in the world. Founded on the growth and development of catalytic converters, South Africa produces in excess of 10% of the world's market, which mainly stems from its dominance in Platinum Group Metals (PGM) production. Catalytic converters are the largest of the auto component groupings exported from South Africa and its value now amounts to $500 million a year. The growth of the local catalytic converter industry has been spectacular, as indicated in Figure 1.

The operating temperatures for catalytic converters are in the region of 900°C, but are associated with frequent temperature variations as automobiles are used intermittently. Thus, the material for this application requires excellent thermal fatigue resistance and high temperature strength. The primary steel used in this application is type AISI 441 stainless steel, which is equivalent to DIN 1.4509. This steel is fully ferritic over a wide range of temperatures.
Type AISI 441 is a dual-stabilised (titanium and niobium) ferritic stainless steel with 18 weight percentage chromium. Titanium and niobium carbides are more stable than chromium carbides and prevent the formation of chromium carbides on grain boundaries, which is the cause of sensitisation of the alloy in near-grain boundary regions. The dual stabilisation imparts beneficial corrosion resistance, oxidation resistance, high temperature strength and formability to the steel.

The effect of Laves Phase (Fe_2Nb) formation on the Charpy impact toughness of the ferritic stainless steel type AISI 441 was investigated. The steel exhibits good toughness after solution treatment at 850°C, but above and below this treatment temperature, the impact toughness decreases sharply. With heat treatment below 850 °C, the presence of the Laves phase on grain boundaries and dislocations plays a significant role in the embrittlement of the steel, whereas above that temperature, an increase in the grain size from grain growth plays an equal role in the impact embrittlement of this alloy.

The toughness results agree with the phase equilibrium calculations made using Thermo-Calc®, whereby it

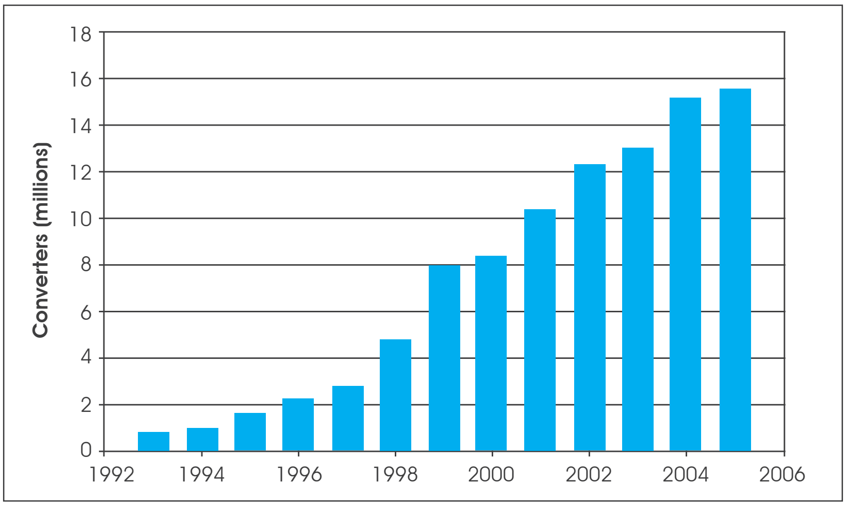

Figure 1. Local catalytic converters growth industry.

was observed that a decrease in the Laves phase volume fraction with increasing temperature corresponds to an increase in the impact toughness of the steel. Annealing above 900 °C, where no Laves phase exists, grain growth is found, which similarly has a very negative influence on the steel's impact properties. Where both a large grain size as well as Laves phase are present, it appears that the grain size may be the dominant embrittlement mechanism. Both the Laves phase and grain growth therefore have a significant influence on the impact properties of the steel, while the precipitation behaviour of the Laves phase has also been investigated with reference to the plant's manufacturing process, particularly the cooling rate after hot rolling or after a solution treatment.

During isothermal annealing within the temperature range of 600 to 850°C, the time-temperature-precipitation (TTP) diagram for the Laves phase, as determined from the transformation kinetic curves, shows two classical C-type noses on the transformation curves.

The first one occurs at the higher temperatures of about 750 to 825°C and the second one at much lower temperatures, estimated to possibly be in the range of about 650 to 675°C. The transmission electron microscopy (TEM) analyses show that there are two independent nucleation mechanisms that occur within these two temperature ranges. At lower temperatures of about 600°C, the pertaining nucleation mechanism is on dislocations. As the temperature is increased to above 750°C, grain boundary nucleation becomes more dominant. The morphology of the particles and the misorientation with the matrix also changes with temperature. At lower temperatures, the particles are more needle-like in shape, but as the temperature is increased, the shape becomes more spheroidal.

The effect of the steel's composition on the Laves phase transformation kinetics shows that lowering the Nb content in these type 441 stainless steels had no significant effect on the kinetics on the precipitation of the Laves phase. However, an Mo addition and a larger grain size of the steel retard the formation of the Laves phase, although the optimum values of both parameters still need further quantification.

The calculational model made for the transformation kinetics of the Laves phase, using the number density of nucleation sites N_o and the interfacial energy *g* as the fitting parameters in this work demonstrated a reasonable agreement with the experimental results. ❸

***Maitse Sello** is a graduate of the Department of Materials Science and Metallurgical Engineering. He is currently employed at BHP Billiton's aluminium smelter in Richards Bay.*

***Prof Waldo Stumpf** is associated with the Department of Materials Science and Metallurgical Engineering of the University of Pretoria.*