ABSTRACT

In internal combustion engines, valves are precision components that regulate gas flow ports and are intended to seal the working space inside the cylinder against the manifolds. Engine valve wear is one of the important factors which reduces the engine performance. In recent years cryogenic treatment is attempted by researchers to supplement the conventional heat treatment to improve the mechanical properties of materials. Recent works have thrown light on the effects of cryogenic treatment on bearings, gears and engine components to reduce wear, and improve performance. The focal point of this experimental study is to investigate the influence of cryogenic treatment on the En 52 and 21-4N valve steels. The En 52 valve steel has been widely used for intake valves and exhaust valve stems in internal combustion engines. The 21-4N valve steel is a heat-resistant steel used as the plate material of diesel engine exhaust valves in the automobile industry.

The most perplexing wear problem in internal combustion engines is concerned with valves, as this wear affects engine performance significantly. One of the most prevalent claims for the cryogenic treatment of metals is an increase in wear resistance. The cryogenic treatment is expected to address wear related problems by virtue of its potential to enhance hardness and precipitation of fine carbides leading to better wear resistance. The variation in different cryogenic treatment parameters (cooling rate, soaking
temperature, soaking period, tempering/aging temperature) showed various degrees of enhancement in the properties of materials. Hence each new material needs to be treated and tested at different temperature levels, different holding times and cooling and heating rates, in order to identify the optimum treatment process parameters which are quite cumbersome because of the large number of experiments. However Design of Experiments provides an optimization technique to minimize the number of experiments needed. The grey Taguchi technique has been used in this work to optimize the cryogenic treatment cycle for these materials.

Preliminary studies are conducted on the En 52 and 21-4N valve steel samples to analyze the effects of shallow cryogenic treatment (SCT) a treatment at -80 °C; and deep cryogenic treatment (DCT) a treatment at -185 °C. The enhancement in the mechanical properties of cryogenically treated En 52 and 21-4N valve steels is analyzed by conducting the wear test, hardness test and tensile test at room and elevated temperature. To study the changes in the microstructure of the cryogenically treated valve steels, a characterization study has been carried out before and after the cryogenic treatment using an optical microscope. The preliminary study shows a better enhancement with DCT than that with SCT. Hence DCT is selected as the best treatment cycle among the two. But it has to be optimized specially for these materials.

The deep cryogenic treatment process is optimized for the best combination of wear resistance, hardness and tensile strength to achieve maximum durability. As per the grey Taguchi technique nine experimental
trials based on the $L_9(3^4)$ orthogonal array are conducted. The optimal deep cryogenic treatment cycle for the En 52 valve steel has a cooling rate of 1 °C/min, a soaking temperature of -130 °C, a soaking period of 36 hrs, and a tempering temperature of 650 °C. For the 21-4N valve steel the optimal treatment parameters are 1.5 °C/min cooling rate, -185 °C soaking temperature, 36 hrs soaking period and 700 °C aging temperature. The enhancement in the mechanical properties of the En 52 and 21-4N valve steels subjected to the optimized cryogenic treatment is quantified by conducting a confirmation test.

The present study concludes that the wear resistance, hardness, tensile strength, and impact strength have improved 47 %, 11 %, 8 % and 23 % for En 52 and 28 %, 15 %, 12 % and 22 % for 21-4N valve steel respectively through the cryogenic treatment. After analyzing the microstructure of the cryogenically processed valve steels using optical microscope and SEM, it is concluded that the formation of very small carbides dispersed in the tempered martensite structure along with retained austenite transformations are the main reasons for the enhancement of certain mechanical properties. The study also concludes that the deep cryogenic treatment induces the precipitation of finer carbides with higher volume fraction and uniform distribution of fine carbides throughout the structure.