CHAPTER 1

INTRODUCTION

There has been a tremendous increase in the growth of the automobile industry. A lot of research has been carried out, with a view to improve the life and performance of automotive components through various treatments. The life expectancy of mechanical systems is always dependent on the most critical component of the system. The service failures of engineering components have always been a challenge to the materials engineer. Apart from various production methods, various processes for improving the service life of the components can reduce this failure. It is believed that the life of the components gets extended substantially with deep cryogenic treatment (DCT). DCT is a supplementary process to heat treatment in which the material is subjected to very low temperature in a particular cycle that consists of well-defined cooling, soaking and heating processes.

1.1 BACK GROUND

In recent years there has been an increase in interest in the application of cryogenic treatment, to enhance the properties of various materials. A number of aerospace, automotive and electronic industries in the USA, China and other developed countries have adopted this process in their regular treatment / production line, to improve life of the components (Cajner et al 2009; Podgornik et al 2009). Cryogenic treatment has significant advantages; the potential property enhancements include increasing the hardness, dimensional stability, wear resistance, fracture toughness, tensile
strength, impact strength and intergranular corrosion resistance. Research efforts are widespread to improve the life and performance of components in automotive applications by various treatments. Recent works have thrown light on the effects of cryogenic treatment on bearing sleeve, gears, valves, piston rings and engine components to reduce wear, and improve performance (Xu et al 2006; Bensely et al 2006; Jaswin et al 2011; Darwin et al 2008; Das et al 2009; Thornton et al 2011 ). The most prevalent claim for cryogenic treatment is that it has been used to improve the wear resistance of the material, because it enhances the transformation of austenite to martensite (Jaswin and Mohan Lal 2011). The formation of very small carbides dispersed in the tempered martensitic structure is the main reason for the enhancement of certain mechanical properties along with retained austenite transformations. Based on the influence of cryogenic treatment, various research works have been completed successfully on different ferrous and nonferrous materials. A review paper by Gill et al 2010 presents various results reported internationally.

The most commonly used material for making fuel injection pump plungers and barrels is 100Cr6 bearing steel. A plunger should have good wear resistance, hardness, toughness, corrosion and dimensional stability. The plunger failure occurs due to many factors which include dimensional stability, wear, corrosion and fracture. Although new materials and production techniques are continuously being developed, these advances have been outpaced by the demands for increased engine performance. The plunger wear related problems leading to failure of the fuel injection pump still remain as a challenge to the manufacturers. The aim of this study was to analyse the improvement in the wear resistance of 100Cr6 bearing steel through DCT and to optimise the DCT parameters for maximum durability of the plunger.
1.2 CRYOGENIC TREATMENT

Cryogenic treatment process is widely used for high precision parts to improve the dimensional stability and wear resistance. This process is limited in application to metals, but can also be applied to a wide range of materials, with differing results. Cryogenic treatment for a component is a one time permanent treatment, imparting microstructural changes in the entire section of the component, unlike coatings. It is an add-on process over conventional heat treatment and not a substitute. In DCT the samples are cooled down to the prescribed cryogenic temperature level at a slow rate, maintained at this temperature for a long time, and slowly heated back to room temperature. Research has shown that cryogenic treatment increases the product life, and in most cases, provides additional qualities to the product, such as stress relieving in cutting tools (Collins and Domer 1997; Gill et al 2011), valves steel (Jaswin et al 2011), piston rings (Darwin et al 2008), etc. Many commercial industries have extolled the benefits of cryogenic treatment, but only a few have extensively studied the mechanism of cryogenic treatment.

Different cryogenic processes have been tested by researchers to supplement the conventional heat treatment, to improve the mechanical properties of materials. Low-temperature treatment is generally classified as either ‘Cold treatment’ at temperatures of about -80°C (dry ice temperature), or ‘Deep cryogenic treatment’ (DCT) at the liquid nitrogen temperature -196°C (Molinari et al 2001). It has been observed from the published literature that low temperature tempering is mandatory for cryogenic treatment, in order to temper the freshly formed martensite, which is highly brittle, and to aid the fine dispersion of carbides. Without low temperature tempering, the product is extremely susceptible to failures, resulting from the impact load experienced.
The most effective treatment cycle for cryo-processing of steel is still under debate. Generally, it can be described as a controlled lowering of temperature from room temperature to the boiling point of liquid nitrogen 77 K (-196°C) in 3 hrs, maintaining the temperature at 77 K for about 24 hrs, and warming up back to room temperature in 6 hrs, either by introducing warmer external gas into the working chamber, or by heating it with radiant heaters, followed by low temperature tempering (Yong et al 2006; Singh et al 2003). The typical cycle is shown in Figure 1.1. The low temperature tempering is done to reduce the brittleness of the freshly formed martensite.

![Figure 1.1 Typical DCT Cycle](image)

Deep cryogenic treatment has been used extensively in automotive components for improving their performance as well as service life. The four main operating factors of the cryogenic treatment process are the cooling rate, soaking temperature, soaking time and tempering temperature. Since low temperature tempering is always done along with DCT the tempering temperature is also considered for all practical purposes as an operating factor for DCT.
1.3 MOTIVATION FOR THE RESEARCH

The plunger is an important component in a fuel injection pump, as it acts as the heart of an internal combustion engine. The plunger is precisely fitted with a very small clearance, to give perfect motion. The failure that occurs in the fuel injection pump is mainly due to the failure of plunger. The plunger failure modes include wear and corrosion. Due to plunger wear, the flow of the fuel increases and it reduces the pressure of the fuel delivered inside the combustion chamber, and results in incomplete combustion, more smoke, increase in fuel consumption, impurities entering the chamber, etc. Even though new plunger materials and production techniques are constantly being developed, these changes face difficulties in keeping pace with the high demands in a worldwide competitive market. Hence, definite ways and measures are needed to improve the performance and life of the plunger by enhancing the wear resistance. Published literature suggests cryo-treatment to enhance the wear resistance in bearing steel that is susceptible for the presence of retained austenite. Hence an attempt has been made to study the effect of cryogenic treatment on 100Cr6 bearing steel.

In order to address the durability and frictional losses an attempt has been made with cryogenic treatment. Cryogenic treatment is one of the ways to improve the mechanical properties, performance and life of the components, by reducing the wear, which in turn, increases the hardness. Various researchers used different levels of the treatment parameters (cooling rate, soaking temperature, soaking period, and tempering temperature) in their studies and claimed different degrees of improvement in the mechanical properties of the steel component subjected to DCT. The level of treatment parameters may vary from material to material. In order to identify the optimum treatment parameters, each new material needs to be treated and tested at different temperature levels, different holding times, and cooling and
heating rates, which is quite unmanageable, because of the large number of experiments involved. In this context it is prudent to develop a DCT cycle that yields this optimum combination of the treatment parameters that results in maximum durability of the component.

However, no work has been reported in the literature for cryogenic treatment of the plunger. In this study, an attempt has been made to optimise the parameters of the deep cryogenic treatment process for 100Cr6 bearing steel using Grey Taguchi technique.

1.4 SIGNIFICANCE OF THE RESEARCH

There has been a relentless pressure in recent years to develop even more fuel efficient and compact automobile engines, with reduced environmental impact and cost. There is also an increasing need for better endurance and performance of automotive engines. Recently, interest in the cryogenic treatment of ferritic and non-ferritic alloys has increased, due to the large potential / promise of enhanced performance. Potential property enhancements include increased hardness, wear resistance, and dimensional stability. If these property enhancements can be achieved, it should be possible to evolve a more energy efficient manufacturing process, to produce value added components at lower cost. Since cryogenic treatment is expected to address wear related problems by virtue of its hardness enhancement and precipitation of fine carbides leading to better wear resistance, an attempt is made to study the effect of cryogenic treatment on the wear characteristics of 100Cr6 bearing steel that is used to make the plunger in automotive fuel injection pumps.

It is to be noted that the service durability of the plunger not only depends on one property but it is a combined effect of different properties. Hence it is not enough if one property is maximized (say wear resistance) but
an optimum combination of these properties, that result in better durability is
to be arrived. In the present work properties namely wear resistance, hardness
and dimensional stability of the material are considered to be optimised for
maximum durability.

The Grey Taguchi technique is adopted in this study, to obtain the
best cryogenic treatment process that gives the optimum enhancement in the
considered mechanical properties leading to maximum durability. The
determination of the appropriate levels of the cryogenic treatment parameters
will not only result in optimum enhancement in the mechanical properties, but
also save considerable time and energy involved in the process. The
significance of this research lies in the fact that the outcome will be helpful
for automotive component manufacturers, in improving the life of the
components using the cryogenic treatment process without conducting an
expensive field test.

1.5 ORGANISATION OF THE THESIS

The content of the thesis is divided into seven chapters and
organized in the following manner.

Chapter 1 deals with the introduction, motivation and significance
of the research work.

Chapter 2 presents a description of the published literature on fuel
injection pump failures, the cryogenic treatment of various materials with a
range of treatment parameters, the mechanisms underlying the deep cryogenic
treatment, the multi-response optimisation using the Grey Taguchi method
adopted for various manufacturing methods, and the objectives of the research
along with the methodology for the study.
Chapter 3 describes the fuel injection pump plunger materials, conventional heat treatment and the cryogenic treatment adopted in the study.

Chapter 4 describes the multi-response optimisation using the Grey Taguchi method.

Chapter 5 deals with the preliminary analysis for conducting the experimental investigation for the deep cryogenic treatment optimisation. The different equipment used for the experimental investigation, such as the Reciprocatory wear test monitor, Vicker’s hardness tester, Dilatometer, Scanning electron microscope, X-ray diffractometer, Optical microscope, Charpy impact test rig, Salt spray corrosion tester and Differential scanning calorimetry are also presented in this chapter.

Chapter 6 presents the preliminary study and grey relational analysis to optimise the deep cryogenic treatment parameters. The results obtained through various tests after the optimised cryogenic treatment are also discussed in this chapter.

Chapter 7 deals with the summary and the conclusions arrived at from the experiments, along with the scope for future work.