Experimental Analysis on the Characteristics of Gas Turbine Blade Materials

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ABSTRACT
Gas turbine technology is gaining importance and has become viable option in most of the applications in view of depleting fossil fuels. Material research has widened the scope and life of gas turbines with improved performance. Present work experimentally studies about the characteristics of different materials that can be used in gas turbines and in particular, turbine/compressor blades. Nickel, titanium and steel alloys of different metal compositions are selected. Hardness test is performed and index is compared. Metallurgical microscope is used for studying the grain structure. Surface roughness test is carried out after grinding and the values of Ra and Rz are compared. Later, heat treatment is carried out and tests are done after the heat treatment as well. Study reveals that suitable alloy can be identified ensuring safer and long withstanding of gas turbine components and blades giving more options in order to meet future power generation requirement.

Keywords: gas turbine materials, material testing, microscopic studies, surface roughness test, turbine blade

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INTRODUCTION

Gas turbine (GT) technology is getting prominence these days because of its wide range of applications and advantages it offers on working and performance. Progress in materials research has paved the way for further improvement of gas turbine performance [1]. The continuous flow of the working fluid requires performing processes like compression, heat input and expansion that take place in separate components. So, material selection is very importance that brings all the components working together in a coordinated way to achieve higher power output. Gas turbine components are subjected to extremely high temperatures causing significant mechanical and thermal stresses. In order to overcome such barriers, gas turbine blades are made using advanced materials and modern consent alloys (super alloys) that contain significant alloying elements [2]. If suitable materials are selected, there are higher chances of withstanding elevated temperatures and thus higher efficiency. Lighter materials like Al alloys would help in reducing weight of the overall engine or system. High performance materials like special steels, titanium alloys Nickel alloys and other super alloys are used for the construction of gas turbines. Different combinations of materials are useful in different components. Metals like Nickel, Chromium, Cobalt and Tungsten are the primary metals necessary for all the components of the GT system. Titanium and Tantalum are also used [3]. Based on the suitability of GT materials, present work chooses Ti, Ni alloy and steel alloys for testing. Ti based alloys have been used as GT materials for the last few decades with varied composition. Nickel based alloys are suitable for all the GT components. Ni based super alloy, Inconel 718 that has wide range of industrial applications, maintaining superior tensile, fatigue and creep properties at high temperature is considered here. Similarly high grade Ti and steel alloys are used.

EXPERIMENTATION

Materials are tested for Hardness, Surface roughness and grain structure, before and after heat treatment.

Hardness Test

Hardness is a characteristic of a material, which is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. Indentation hardness value is obtained by measuring the depth or the area of the indentation. Proper hardness index ensures resistance to deformation, friction and abrasion. In the hardness test, force is applied mechanically on the specimens. Rockwell hardness tester presents direct reading of hardness number on a dial indicator and its indentors are made of hardened steel or diamond. For testing different materials used in this work, commonly 'C' scale (hardness is presented as HRC) is used and applied force is of 150 kgf. The Rockwell hardness test method is the most commonly used hardness test method.

Microscopic Studies

Refined grain size means improved mechanical properties and response to thermal treatment with reduced wear and tear. In this work, Leica Metallurgical microscopy is used to examine the micro-structure materials in order to understand the relationship between properties and structures that are coarse enough, not visible to the naked eye. Magnifications are used between 5× and 100×.

The specimen is prepared using processes like:

- Sawing the sectional area to be examined.
- Coarse grinding and grinding progressively finer with emery paper up to 2500 grade.
- Polishing using alumina powder or diamond paste on the rotating wheel.
- Etching in dilute acid (Kellers Etch for titanium, Glyceregia for Ni and stainless steel alloys).
- Washing in alcohol and drying.

Surface Roughness Test

Surface roughness is the component of surface texture, i.e. surface irregularities of small wavelength. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Mean surface roughness and surface roughness depth in terms of Ra and Rz are measured by Marsurf ps1. This test also plays vital role as roughness is considered to be detrimental to part performance.

Heat Treatment

To harden or soften the material the material, heat treatment plays an important role, in which materials are heated from normal to extreme temperatures to achieve desire result. Metals and alloys are mare of small crystals, commonly known as grains. Nature of the grain size and composition of metal can determine the entire mechanical behavior of metal and alloy. After heat treatment, mechanical properties change due to heat at high temperature and cooling in a different medium. In the present study the specimens are heated at 950°C in a furnace for about 3 hours and made to cool in air indefinitely at room temperature. Keeping in view, the alloys under considered in this work, the temperature and time are finalized. However, maximum combustion section outlet temperature (turbine inlet temperature) in a GT engine is slightly above 1000°C.

Specimen Preparation

Specimens are prepared as shown in Figure 1. The three alloy materials are cut into 20×10 cross section by wire electric discharge machine. After that, coarse grinding operation is performed to remove any scale formed on the work surface. Then, fine grinding and polishing are done to measure surface finish and hardness. In the end, all the three specimens are etched with proper chemical solutions.

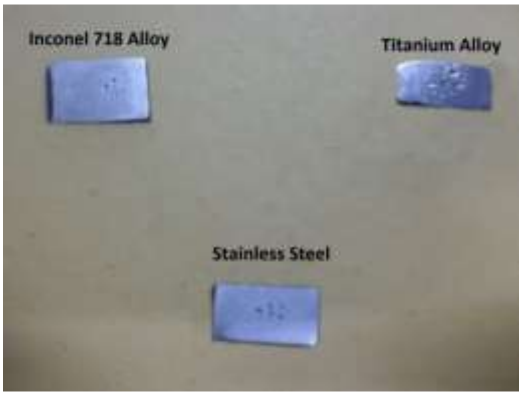

Fig. 1. *Specimen of three alloy materials.*

RESULTS AND DISCUSSION

Microscopic images of steel, Nickel and Titanium alloys are discussed here. Images are obtained before and after that treatment. Grain structure has got clearer with heat treatment as observed in all the three cases. Before the heat treatment, the grain size area of Titanium is bigger than the other three alloys. Inter-molecular distance also plays crucial role in the strength of the material. This is seen improved with heat treatment. Details of the three microscopic views are given in the following section.

Stainless steel is also iron based alloy and it has austenitic structure. Figure 2 represents the martensite microstructure after heat treatment in fine scale, which is formed within the earlier austenite grain. Carbide formation is also observed in the form of small dots shown. Main effect of heat treatment on stainless steel is to convert austenite to martensite that has better surface finish with increase in hardness. Ni based super alloys have a fully austenitic face centred cubic (fcc) structure which is illustrated in Figure 3, before heat treatment. At a high temperature, homogeneously distributed coherent hardening induces brilliant mechanical properties. Due to heat treatment at 950°C, the grain boundaries are changed and refined. All grains are equally distributed on surface, which is seen the surface roughness test, where surface roughness is decreasing after heat treatment.

Titanium alloys are heat treated to reduce residual stresses, increase ductility, machinability, dimensional and structural stability and optimize the properties like fracture toughness, fatigue strength, and high-temperature creep strength which is very essential for gas turbine blade. As seen in Figure 4, the close-pack hexagonal structures are more close to each other after heat treatment process. Due to this, the hardness number has increased slightly and surface finish has been better than before. In all the alloys grain size varied with heat treatment.

Fig. 2. *Microscopic image of stainless steel alloy with heat treatment.*

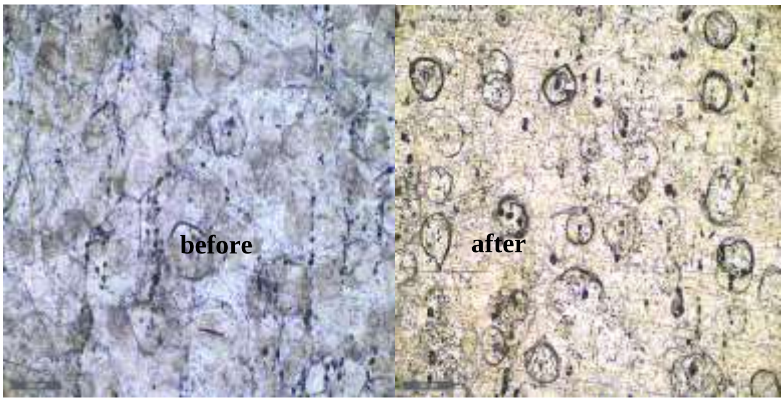

Fig. 3. *Microscopic image of Ni alloy with heat treatment.*

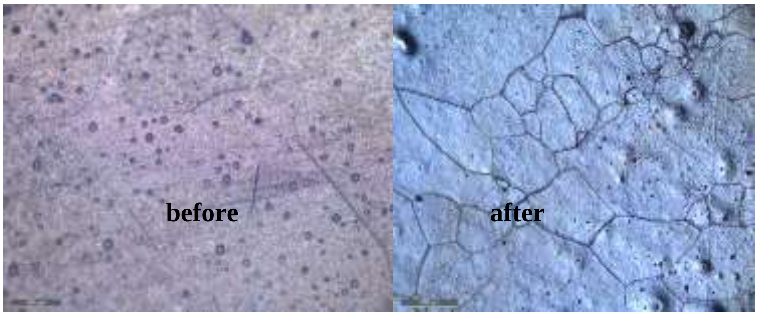

Fig. 4. *Microscopic images of Ti alloy with heat treatment.*

Hardness indices, before and after heat treatment are shown in Table 1. Hardness of steel alloy increased drastically from 9 to 85, which is not desired in the GT components. Similarly, hardness of Ni alloy increased with rise in temperature. Ti alloy showed only slightly increased hardness, which is a favourable component for usage in turbine blades. Table 2 shows the surface roughness results, before and after heat treatment. The surface roughness of steel alloy increased more with heat treatment. Ni alloy proved to be better than steel alloy, but not like Ti alloy, where the roughness is similar, before and after heat treatment. However, before and after applying heat, the roughness of steel alloy > Ni alloy > Ti alloy.

Table 1*. Hardness before heat treatment and after heat treatment.*

Alloy	Before heat treatment	After heat treatment
Stainless steel alloy	9.05	85
Ni alloy	25.5	82.5
Titanium alloy	35.75	40

Table 2. *Surface roughness before and after heat treatment.*

Alloy	**Before heat treatment**	**After heat treatment**
Stainless Steel alloy	Ra=0.029 Rz=0.19	Ra=0.045 Rz=0.53
Ni alloy	Ra=0.025 Rz=0.20	Ra=0.024 Rz=0.26
Titanium Alloy	Ra=0.023 Rz=0.22	Ra=0.027 Rz=0.22

CONCLUSIONS

Different gas turbine materials are tested for hardness, roughness and grain structure. Grain structure is observed using Metallurgical microscope. In steel alloy, the main effect of heat treatment is to convert its earlier austenitic structure to martensitic that has better surface finish with increased hardness. In Ni alloy, the grain boundaries are changed and refined with heat treatment. All grains are equally distributed on surface, decreasing surface roughness. Using Rockewell harness tester, hardness is measured and compared. Ti alloy showed similar hardness number, before and after heat treatment. Hardness of steel and Ni alloys increased drastically with heat treatment. Surface roughness test is carried on all the three specimens after preparing them with grinding, etching and washing. Roughness of steel alloys increased more with application of heat. Surface roughness of Ni and Ti alloys is not much dependent on the heating aspect. Results reveal that Ti alloy are more useful for taking higher loads with abilities to withstand high temperatures. Thus, the present work establishes the way of testing different alloy materials suitable for gas turbine components.

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