LASER SURFACE MODIFICATION OF GRAY CAST IRON USING Nd: YAG LASER FOR ENHANCED SURFACE PROPERTIES

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ABSTRACT

This report presents laser surface modification on gray cast iron using Nd: YAG laser for enhanced surface modification. Material used in this work was gray cast iron from automotive brake disc. Experiments were performed using was Nd: YAG pulsed laser under different processing conditions. The parameters of interest were the laser peak power of 670 W, 800 W, 1000 W, Pulse repetition frequency of 50 Hz, 60 Hz, 70 Hz and travel speed 1000 mm/min, 1200 mm/min, 1400 mm/min. Various modification layers of gray cast iron were analyzed with respect to microstructure, hardness value, hardening depth, and surface roughness. Results of laser incidence under different processing conditions are presented. Different microstructure achieved by applying range of laser treatment selected parameter. A good increase of micro hardness in the entire performed test was verified at Peak power of 830 W, speed and pulse repetition frequency of 1400 mm / min and 50 Hz respectively. A minimum depth at 134.262 µm and maximum hardness at 423.014 $HV_{0.3}$ was produced. These findings were important to increase wear resistant of brake disc surface.

ABSTRAK

Kajian ini membentangkan pengubahsuaian laser keatas besi tuang kelabu menggunakan laser Nd:YAG untuk meningkatkan sifat-sifat permukaan. Bahan yang digunakan dalam kerja-kerja ini adalah besi tuang kelabu dari cakera brek automotif. Ia juga untuk mencari parameter proses yang optimum dan untuk menilai ciri-ciri pengubahsuaian laser didalam besi tuang kelabu. Eksperimen telah dijalankan menggunakan adalah laser Nd: YAG di bawah keadaan pemprosesan parameter yang berbeza. Parameter yang digunakan dalam kajian ini adalah kuasa laser 670 W, 800 W, 1000 W, PRF iaitu 50 Hz, 60 Hz, 70 Hz dan kelajuan pada 1000 mm/min, 1200 mm/min, 1400) mm/min. Pelbagai lapisan pengubahsuaian daripada besi tuang kelabu dianalisis berkenaan mikrostruktur, nilai kekerasan, kedalaman pengerasan, dan kekasaran permukaan. Keputusan kajian laser dengan keadaan pemprosesan yang berbeza yang dapat dibentangkan. Parameter berbeza yang digunakan untuk rawatan laser akan memberi mikrostruktur yang berbeza. Peningkatan kekerasan dalam ujian yang dilakukan keseluruhan telah dapat dicapai pada kuasa laser pada 830 W, kelajuan dan PRF pada 1400 mm/min dan 50 Hz dimana menghasilkan kedalaman yang minimum iaitu pada 134.262 µm dan kekerasan yang tinggi pada 423.014 $HV_{0.3}$. Pencarian ini sangat penting untuk meningkatkan ketahanan kehausan pada sesebuah brek rotor.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

This project focused on experimental for surface modification of material surface using laser processing. It is also discuss the concept and practically on laser processing that a modified surface layer with high mechanical properties that can be produced thus withstand wear and temperature by these modifying process. The high power heat source produced by a laser beam is ideal for surface modification. Laser heat treatment is a surface modification process through a process of heating and cooling controlled to alter the microstructure of the metal. An advantage that can be explained is the ability of lasers to heat treatment localized areas without affecting overall sample of material or work piece (A. coupling and W. Reitz, October 1999). After the heat treatment process, the process of "quenching" or rapid heat removal is carried out. Diode laser, Fiber Lasers and CO2 laser is usually used nowadays to provide heat treatment (A. coupling and W. Reitz, October 1999). Laser used for this research is Nd: YAG laser system.

1.2 PROBLEM STATEMENT

Disc brake is one of the important parts in a vehicle that is required to stop the vehicle during travelling. It operates by transforming the kinetic energy into heat. Brake pads needed to stop the iron rotor attached to the wheels of the car and this stimulates the friction between the rotor and the pad. Excessive braking resulted in high temperature which led to rotor failure. Wear resistance is an important factor to determine brake rotor lifetime and can also be related to hardness properties. Vickers hardness test taken for gray cast iron material was 200-250 HV (www.google.com/patents/US4605105?dq). Previously, many methods was used to increase the wear resistance such as conventional heat treatment that using furnaces vacuum, and by this project, laser surface modification was used for heat treatment as an improvement. In addition, by this project, parameters that suitable such as temperature elevation, the height of power, the laser beam speed was investigated.

1.3 PROJECT OBJECTIVE

The objective of the project is to laser process gray cast iron sample surface using Nd: YAG laser for enhanced hardness properties and minimum surface roughness.

1.4 SCOPE OF PROJECT

In order to achieve the objectives of this project, the scopes are as following:

1. Develop a design of experiment (DOE) for laser processing of gray cast iron.
2. Laser process gray cast iron samples using Nd: YAG laser system.
3. Characterise laser modified samples for;
    - Metallographic study
    - Micro-hardness properties
    - Surface roughness properties
4. Conduct ANOVA analysis for DOE processing parameters.
5. Optimise the parameters for minimum surface roughness and minimum hardness.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides detail description of literature review according to the title of laser surface modification of gray cast iron using Nd:YAG laser to enhance surface properties. This literature review will give an overview about the basic concepts of the principal techniques of laser that are used in this works. The focus of the chapter is on the laser treatment that possibility changes the microstructures of the gray cast iron, hardness and surface modifications.

2.2 LASER AND ITS APPLICATION

Laser is one of the biggest innovations in the 20th century, but it continuous development has an interesting chapter in the history of technology, science and engineering. Laser has emerged as a promising tool to be applied in various fields. Basic laser theory was presented by Einstein, followed by Kopfermann and Ladenburg. The first confirmation were presented by Einstein. In 1960, Maiman has developed the first ruby laser. It was further developed in 1962 to 1968 on the basis of laser (J Dutta

Majumdar and I Manna, 2003). There were many lasers that were created in this era, including CO2 lasers, Nd: YAG laser, Semiconductor Lasers and others. After 1968, the already existing laser has been designed and built back better durability. In mid-1970, the emerging laser applications in industries such as the use of welding, cutting, drilling and marking can practically in the industry. In 1980 until early 1990, development of the laser can be explored more in-depth for surface-related applications such as cladding, heat treatment, glazing and thin film deposition.

2.2.1 LASER SURFACE MODIFICATION

Laser surface modification process is a very productive and the work that has been done is to improve the surface characteristics of materials in enduring the heat, wear and Friction through surface modification. The other factors that need to considered other than practical usage were the time and cost of the significant features have been developed involving surface engineering application. Due to the rapid progress in laser surface modification, the former technique using conventional methods for surface treatment such as carburizing and hardening flame has now been upgraded using a heat source such as a laser sources, ions, and electrons. High power lasers now have to prove that the use of lasers for cutting not only material, but can provide other surface modification proved to be capable of Producing wear, corrosion, fatigue, adherent and fracture resistant coatings on a diverse range of materials (DTA Matthews, V.Ocel'ık, and J.Th.M. deHosson, 2007).

Lasers have unique characteristics due to laser beam of electromagnetic radiation is absorbed in the top atomic layer of opaque materials such as metals for heating surface. Precisely focused energy used on the surface only where it is needed. Advantage in the use of laser surface modification is chemical cleanliness, controlled thermal penetration, reduced use of other machines for finishing work and easy to automate.

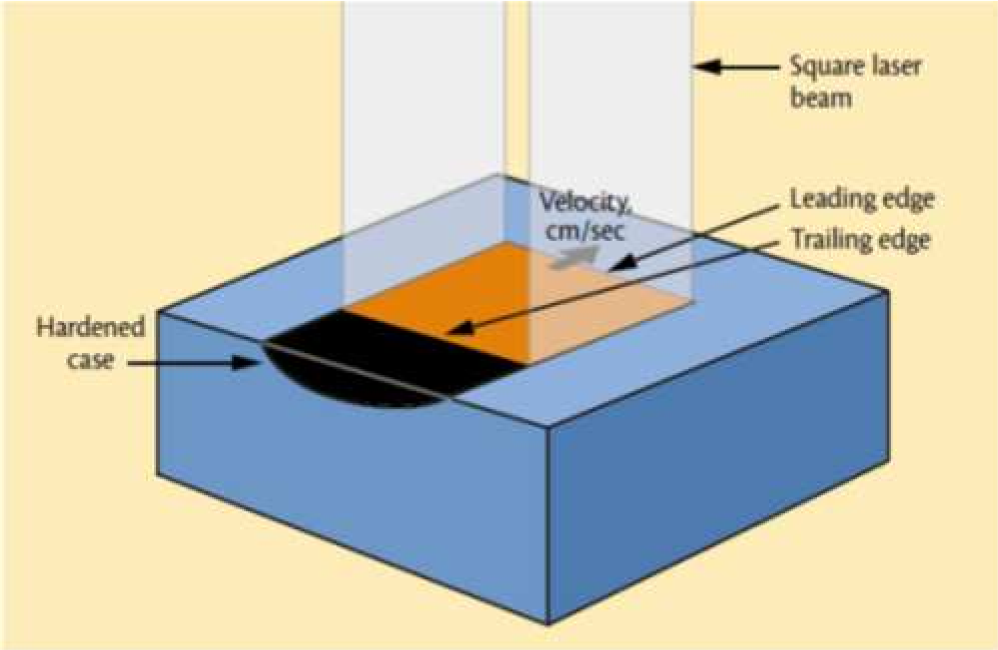

Figure 2.1: Interaction between laser light and material to produce a hardened case*(O.Sandven).*

Figure 2.1 shows the interaction of light with the material to produce a hardened layer. The energy absorption occured started at from the point of leading edge and ended at the trailing edge. The beam Produce the shape of the hardened zone varies with the shape of the spot and the energy distribution Across the spot. There are many ways that can be used to modify the beam (O. Sandven, Laser Surface Transformation Hardening, Metals Handbook, 9th Ed., Vol. 4: Surface Engineering, ASM, pg. 507-517) but the most common are rounded and square, square spot produces a relatively flat based and produces a circular spot hemispherical shaped hardened zone. This was an answer of the energy absorbed per unit area Across the Surface Perpendicular to the direction of travel. An the best treatment of the thermodynamics and kinetics of this process was given in (O. Sandven, Laser Surface Transformation Hardening, Metals Handbook, 9th Ed., Vol. 4: Surface Engineering, ASM, pg. 507-517). This is because it is typical of laser Heat Treating is performed without the use of an external quenching, a good rule-of-thumb is the case depth that's-to-depth ratio, section should be approximately 1:10 for internal or self-quenching of the most materials. This ratio was based on the plain carbon steel of medium carbon content, and nucleon with increasing harden ability.

2.3 LASER SOURCES

The laser processing experiments were carried out using a Nd:YAG (neodymium-doped yttrium aluminium garnet). Heating, melting and vaporization that occur in solid, liquid and vapor states is a factor in the processing mechanism of a principle of laser material processing(Ion, 2005). The parameters considered in the laser process are beam size, processing speed (rotation velocity) and laser power (A. Blarasin, et.Al. 1982). The combination of their set temperature field in the interaction between the laser beam and the material and determine the depth of melting and cooling of the surface layer rate, the rate of cooling determine the properties of the metals and the presence of defects in the liquid layer possibility for a given form in the treated area. Surface treatment was commonly used to increase the hardness, wear resistant, and corrosion properties of the surface material of cast iron components to provide a high and increasing reliability in industries in need such as high pressure and high load (WX Pa. et. Al, 2005).

2.4 EFFECTS OF LASER PARAMETERS ON THE SURFACE PROPERTIES

The laser processing parameters were varied to produce different depths of laser treated layer (J.H. Abboud, et.Al, 2007). The laser parameter that involved in the process was laser beam wavelength, temporal pulse power (pulse length, peak power and pulse shape), repetition rate beam energy distribution, and beam geometry (focal spot size, depth of focus) (F.O. Olsen, and L. Alting, 1995). There were two types of laser mode that been used in laser surface treatment which were the continuous and pulse mode laser. Both continuous and pulsed wave lasers can be used for surface modification. Average power and peak power was determined by the pulse energy where it increases both peak power and average power and this increase treated dimensions zone. The obvious advantage was to use the continuous laser beam is because of amorphous available in a continuous process compared to the laser pulse spot. Bubbles, depressions, and porosity is a simple defect occurs with continuous wave laser, so by using a pulsed laser, a high-quality glass layers have been successfully produced.

The frequency of laser which controls the overlapping between laser spots was further consideration in pulsed mode. The overlapping technique with multipass is an effective method to enlarge the amorphous area of laser glazing treatment (Y. Yang, et.Al). The sample surface roughness was also increased with the increase of crack density, as a consequence of the increase of beam scanning speed and overlap (Y. Yang, et.Al). Defects morphology on surface will be able avoided and properties of micro hardness and surface roughness will be greatly improved with study the process parameters laser.

2.5 GRAY CAST IRON

Gray iron, also known as gray cast iron is an alloy of iron with graphitic microstructure. It was named after it broke gray mould, which caused by the presence of graphite. Gray iron is the most common cast iron and cast most widely used base material weight. It is usually used for housing where the tensile strength is not critical, such as an internal combustion engine, the cylinder block, and valve bodies, Grey casts iron's high thermal conductivity and specific heat capacity are often exploited to make cast iron cookware and disc brake rotors (D.E. Krause, 1940-1973). between the advantages and disadvantages are gray iron was common engineering alloys for a relatively low cost and in a good machine, the result of cut and split graphite lubricant chips. Apart from that it also has good galling and wear resistance for self-lubricating graphite flakes. But also provide iron graphite gray excellent damping capacity because it absorbs energy. It also experienced less solidification shrinkage of cast iron that does not form a graphite microstructure. Silicon also promotes good corrosion resistance and increase instability when casting. Generally, Gray iron considered easier to weld. Being compared with the more modern steel alloys, gray iron has a low tensile strength and elongation, therefore, impact and shock resistance was almost non-existent.

Grey cast iron was widely used in components such as pistons, guides, valves, tool beds; due to its good properties, such as excellent machinability and cast ability, as well as low price (A. Liu, et.Al, 2010). from one point of view, gray cast iron is the oldest cast ferrous products. Despite competition from new materials and their energetic promotion, gray iron was used for those applications where the attributes have proven it to be the most suitable material. While for wrought steel, gray iron most widely used for engineering purposes. In 1967, production of gray iron castings was more than 14 million tons, or about two and one-half times the amount of all other types of castings combined. There are several reasons that have been listed for the popularity and widespread use. It has some features that are required that are not owned by any other metal and yet is among the cheapest of ferrous materials available to engineers. Gray iron castings are readily available in nearly all industrial areas and can be produced in foundries represent a relatively modest investment. It was the purpose of this paper is to bring to your attention the gray iron features that make the material very useful.

Gray iron was one of the most easily removed all the metal on the foundry. Gray iron has a lowest temperature of ferrous metal pouring, which is reflected in the high volatility and the ability to cast into complex shapes. As a result during the final stages of solidification oddity, it has a very low and, in some cases, no liquid to solid shrinkage so that the castings are easily available. For most applications, gray iron used in as-cast condition, thus facilitating production. By the Gray iron has excellent machining qualities producing easily disposed of chips and produce surface wear with outstanding features. With this, the resistance of gray iron scoring and galling with proper matrix and graphite structure is universally recognized.

2.6 AUTOMOTIVE DISC BRAKES

Generally, modern cars have disc brakes on the front wheels and now was increasing has disc brakes on the front wheels and the rear wheels as well. The main purpose of the car is a disc brake to slow the vehicle by transforming the kinetic energy into heat friction. A brake disc (rotor) installed rooted and rotating with the wheel. Two brake pads (layer) is placed in the calliper mounted on the knuckle, which is installed in the chassis. When the driver applied the brakes, the brake cylinder pressure increases and the piston pushes the pad to contact with the disc. The subsequent friction between the brake pads and brake discs exert torque on the disk, which is connected to the wheel, and the subsequent friction between the tire and the road makes the car slow down. Discs used in most cars are made of gray cast iron.

Figure 2.2: Brake Disc *(M.A. Maleque, 2010)*

Various compositions can be produced by commercial gray iron. Foundries to meet the same specification can still use different compositions to take advantage of low-cost raw materials locally available and the general nature of the types of castings produced in the foundry. Due to that, the inclusion of the chemical composition in the purchase specifications for casting should be avoided unless essential to the application.

The compositions which one may find in gray iron is as follows: total carbon, 2.75 to 4.00 percent; manganese, 0.25 to 1.50 percent; silicon, 0.75 to 3.00 percent; phosphorus, 0.02 to 0.75 percent; sulphur, 0.02 to 0.20 percent. One or more of the following alloying elements may be present in varying amounts: molybdenum, copper, nickel, vanadium, titanium, antimony, and chromium.

2.7 MECHANICAL PROPERTIES OF GRAY IRON

Property in which a material is important to the user of casting such as hardness, wear resistant, strength and modulus of Elasticity. These properties are quite different for gray cast iron to steel. The outstanding performance of gray iron in applications involving sliding surfaces, such as machine tool ways, piston rings and cylinder bore. As well as the performance of internal combustion engines and machine tools is remarkable when one considers the machining of gray iron facility. It is also known for it resistance to galling and seizing, but many explanations have been given for this behavior, such as lubricating effect of graphite flakes and oil retention in the graphite area. This is very probably true, but it is also possible that the graphite sheets allow some small inn pearlite matrix in the contact between the mating surfaces. It is rarely possible to get the perfect fit, and, often, high spots in the mating metal surfaces can result in high unit pressure cause seizing.

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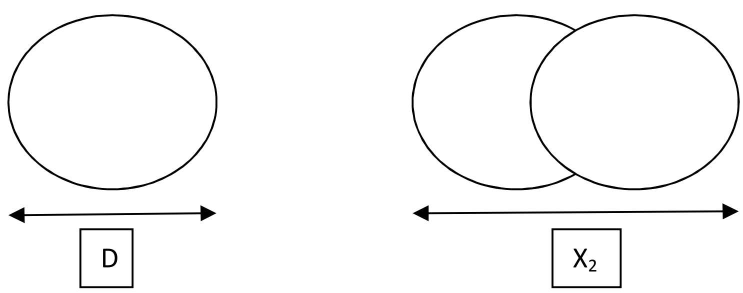
2.8 MACHINING OF GRAY IRON

As we can see ferrous materials that are widely used for construction purposes, iron gray for a given level of force is one of the most easy machinable, usually gray iron was cutting free in that small chip and easily removed from the cutting area. In addition, there is some difficulty with the chip surface marring finish. Even free cutting behavior was the result of random flakes of graphite matrix continuity. Although very successful gray iron machined without coolants, they may be found necessary if the high rate and tolerance machining required. Cooling just not only helps in the removal of the chip, but also control the temperature of the casting, which is required to work on a close tolerance.

Although gray cast iron was good machinability, many problems in machining analyzed as the inability to get the tool life, the hard edge, and difficult to maintain dimensional tolerances required. Selection of one grade, the weaknesses in the design of casting or machining improper procedure is a significant problem among the factors that can be collected. So, in order to curb this problem, the recommended tool depends on the speed, the depth of a cutting for gray iron, feeds, and all sorts of simple machining operations (Angus, HT, Physical and Engineering Properties of Cast Iron,1960).

2.9 MICROSTRUCTURE AND MICRO HARDNESS

Overlapping means of laser forming process are overlap each other. To express mathematical theory in this overlap, it can be linked according to the following equation. The large diameter formed called the laser spot diameter, where a spot is D. When the diameter of the laser in a row, then two laser spots are formed X_2. Therefore, $\Delta = (X_2\text{-}D)$ known as overlap length. So, the formula percent to overlap is $\dot{\eta} = (1 - \Delta / D) \times 100$.



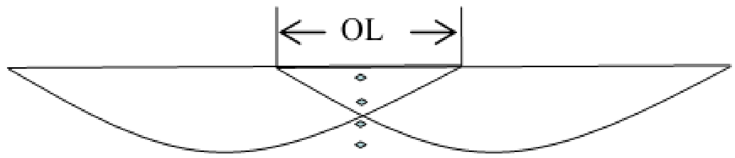


Figure 2.3: Overlap length

Figure 2.4: Optical micrograph showing overlap(*M. A. Montealegre)*

Considering the combination of uniformity of hardening depth and uniformity of hardness, the parameters for the overlapping process can be optimized. Larger overlapping length ensures a uniform hardening depth, but for a given surface, it also means more hardening tracks, this induces a greater overlapping zone with hardness reduction. In case of diode laser hardening with a rectangular laser spot and uniform energy distribution, the depth of the hardening is more uniform. When the overlapping length exceeds this point, it induces more overlapping zones and hardness reduction (A. Liu, B. Previtali, 2010)

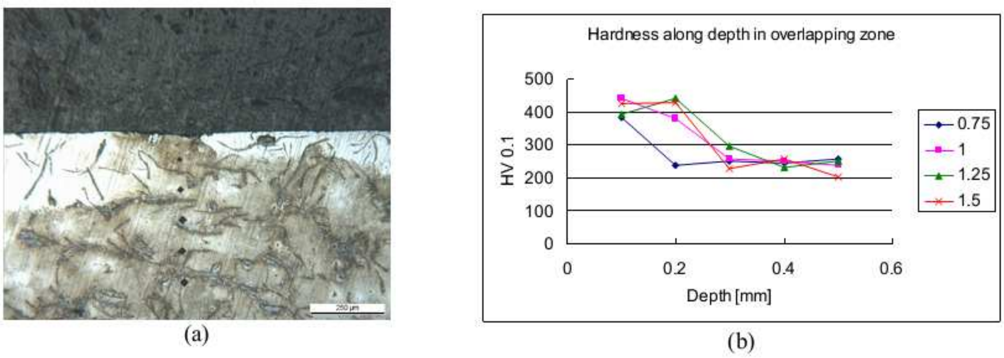


Figure 2.5: Hardness test (a) and hardness profile (b) in overlapping zone(*M. A. Montealegre)*

Different aspects of the microstructure will be produced because the laser tracks or the incidence of individual pulses using the same processing parameters. This occurs due to the influence of the residual heat when the laser tracks were applied. Parameters such as overlapping and scan velocity will be possibility responsible for these microstructure modifications (Waldemar A. Monteiro, 2009).

In general, the microstructure of the laser surface hardened layers is a result of the following process. First, the specimen was quickly heated and most of the starting pearlite is transferred into austenite. The austenite then changes into martensite during subsequent rapid cooling, including certain unchanged austenite that is retained. Moreover, if there were exists certain phosphorous eutectic in the laser impact area, then it is dissolved and transferred into ledeburite or coarse needle-shaped martensite due to their low melting point. Sheet graphite can be partly dissolved and diffused as a result of the boundary reaction due to a very high temperature. Thus, the typical microstructure of the laser surface hardened layer is composed of martensite or ledeburite, retained austenite, and graphite sheets (LIU Xiu-bo, 2007)

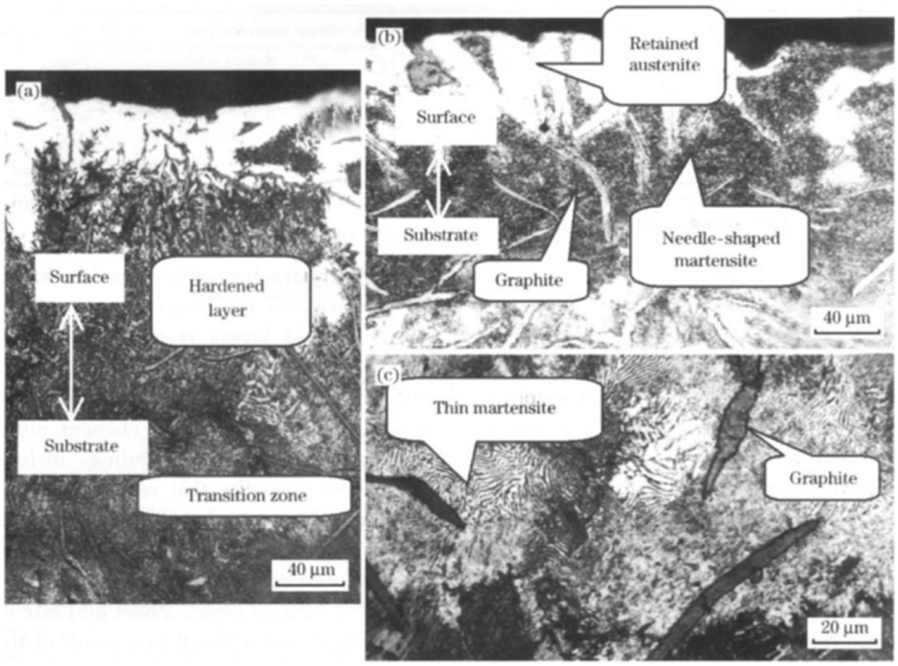


Figure 2.6: Optical microscope micrographs of gray cast iron after laser surface hardening processing *(LIU Xiu-bo, 2007)*

2.10 SURFACE ROUGHNESS

Surface roughness also known as surface profile (Ra) that was a measurement of surface finish and it was topography at a scale that might be considered "texture" on the surface. Surface roughness was a quantitative calculation of the relative roughness of a linear profile, expressed as a single numeric parameter. Defects on the surface of the material can occur during processing or after used, and analysis of these defects is very important in the delivery of information to improve the efficiency, effectiveness and durability of the surface.

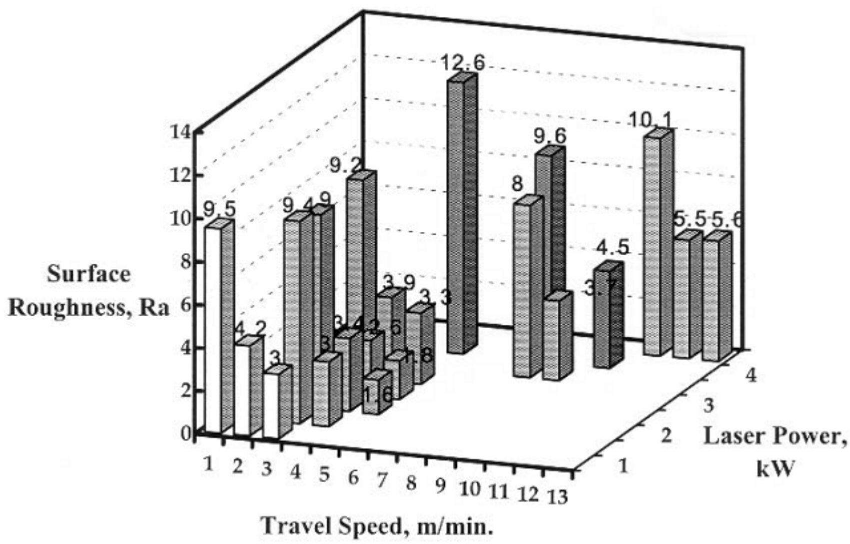


Figure 2.7: Variation of the surface roughness of the laser-hardened layer with laser power and travel speed *(Jong-Hyun Hwang)*

Figure 2.7 shows a variation of the surface roughness of the hardened layer of cast iron as a function of laser power and travel speed. The surface roughness of the layer decreases with an increase in travel speed for a given laser power and also increases with a decrease in laser power for a given travel speed. Lower travel speed and higher laser power cause surface melting of the layer. For a proper combination of