Effect of Heating Time on Hardness Properties of Laser Clad Gray Cast Iron Surface

B. Norhafzan¹, S. N. Aqida², F. Mifthal³, A. R. Zulhishamuddin⁴, I. Ismail⁵

¹,²,³,⁴Faculty of Mechanical Engineering, University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
²Department of Mechanical Engineering, Politeknik Muadzam Shah, 26700 Muadzam Shah, Pahang, Malaysia
³Faculty of Manufacturing Engineering, University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

norhafzan23@gmail.com

Abstract. This paper presents effect of heating time on cladded gray cast iron. In this study, the effect of heating time on cladded gray cast iron and melted gray cast iron were analysed. The gray cast iron sample were added with mixed Mo-Cr powder using laser cladding technique. The mixed Mo and Cr powder was pre-placed on gray cast iron surface. Modified layer were sectioned using diamond blade cutter and polish using SiC abrasive paper before heated. Sample was heated in furnace for 15, 30 and 45 minutes at 650 °C and cool down in room temperature. Metallographic study was conduct using inverted microscope while surface hardness properties were tested using Wilson hardness test with Vickers scale. Results for metallographic study showed graphite flakes within matrix of pearlite. The surface hardness for modified layer decreased when increased heating time process. These findings are significant to structure stability of laser cladded gray cast iron with different heating times.

1. Introduction
Gray cast iron usually used for automotive and most engineering component were operate in high temperature condition such as brake disc, stove part and die application. The ability to withstand in thermal cyclic condition caused gray cast iron suitable use in high working temperatures in manufacturing process. However when the temperature is above 600°C, the grey cast iron are easy to wear and collapse due to brittleness, thermal wear and fatigue, so the grey cast iron life at high temperature is not long enough. Laser cladding was implemented to improve die life due to excellent bonding, improve hardness, absence of flaws, produce new mechanical properties and high temperature stability of surface layer [1]. Laser melting on gray cast iron surface shown hardness increased after laser processed [2].

Thermal stability is the important factor of material to stabilized its molecule at high temperature. Study of thermal stability for various material shown hardness of the sample decreased when the temperature increased [3]. Thermal stability is a tendency for modified surface to retain it properties at high working temperature. Thermal stability on Ti-6Al-4V improve after cladding process with TiVCrAlSi [4]. Alloying element such as Molybdenum and chromium improve strength, hardness, toughness and hardenibility also improve thermal stability [5]. Another thermal stability study shown, increased annealing temperature caused decreased microhardness and enlarge grain in Ni-based alloy
The thermal stability of die material at elevated temperature was investigated through microhardness testing and metallographic study. The combination of wear resistance, high strength and thermal stability can increase significantly the lifetime. This study investigates the hardness properties of laser cladded grey cast iron with Mo-Cr powder addition after heating at 650 °C temperature and different heating time of 15, 30 and 45 minutes.

2. Experimental
Laser cladded surface of gray cast iron with Mo-Cr powder was used as a material in this study. The cladded samples were cut using diamond blade. Samples surface were prepared using abrasive papers of 400, 800 and 1200 grit size, and polish using red felt with and imperial cloth with 6 and 1 µm diamond paste before and after heating. The 4% alcoholic nitric acid (nital) used for 5 seconds at room temperature to etched sample before surface characterization to reveal the ferrite grain boundaries and reveal phases. Samples were then heated for 15, 30 and 45 minutes using verbatim furnace at 650°C. After that, metallographic study was conducted to verify the grain size and phase structure. Metallographic study was conducted using ECON-2010L0 optical microscopes with image analysis software at 100 µm. Surface hardness was analysed using Vickers scale of Wilson Hardness tester with 100 kN load.

3. Result and Discussion
3.1. Metallographic Study
Micrograph in Figure 1 indicates cross-sectional surface of laser clad grey cast iron with three layers namely substrate or based materials (BM), heat affected zone (HAZ) and cladding zone (CZ). The heat-affected zone is a transition zone where substrate was not fully melted and the chemical properties were altered by high temperature heat [8]. The cladding zone produced fine grain structure with high metallurgical bond. The cladding zone is important to shown the effect of Mo-Cr powder addition via laser cladding process at heating temperature of 650°C.

![Figure 1](image-url)

**Figure 1**: Cross-sectional of laser clad grey cast iron with three layers namely cladding zone, heat affected zone and based materials (substrate)
Substrate of grey cast iron has an interconnected flake graphite shape. After laser processing, some gray cast iron structure were mixed together with Mo-Cr and produced new microstructure with grain refinement [9]. Grain refinement in the cladded layer is shown as white layer with graphite phase due to rapid heating and cooling during laser processing [10]. The metallographic study was performed to analysed clad surface microstructure after heated at 650°C for 15, 30 and 45 minutes. Figure 2 shows transformation of grey cast iron microstructure after heated at elevated temperature and cooling down at room temperature.

The microstructure before and after heating of 15, 30 and 45 minutes at 650°C is shown in Figure 2 (a) to (d). Increasing heating time produced larger ferrite structure. Figure 2 (d) shows the effect of the longest heating time of 45 minutes on ferrite size of cladded gray cast iron with Mo-Cr powder addition. Decrease of graphite flake in clad layer produced hard phase on surface layer. Graphite flake increased when the duration of heating time increased. The microstructure of grey cast iron is a matrix of pearlite with the graphite flakes. Ferrite can only absorb a very low amount of carbon at room temperature, the un-absorbed carbon separates out of the body centered cubic structure to form carbides which mixed together to create small pockets of an extremely hard crystal structure called cementite [11]. However, when ferrite is heated the body-centered-cubic structure changes to a face-centered-cubic structure, thus allowing for absorption of the carbon into the crystal structure. Decreased graphite phase near the surface contribute to prevent wear and increased lifetime [2].

![Figure 2: Micrograph of Gray cast iron with Mo-Cr (a) before heated at 650°C, (b) after heated 15 minutes, (c) after heated 30 minutes and (d) after heated 45 minutes](image)

3.2 Hardness properties

The hardness properties of modified layer decreased directly proportional to heating period. Surface hardness in cladded zone increase due to brittle martensite structure formation. Surface hardness properties of gray cast iron before laser surface cladding were approximately 177 HV0.1. Surface hardness of cladded layer increased up to 1000 HV0.1 after cladding process. The surface hardness of
melted layer reported previously was increased up to 737 HV$_{0.1}$[2]. Hardness of modified layer increased up to four times of the substrate hardness due dissolved carbon content in melted zone. After heated to 650°C for 15, 30 and 45 minutes, the surface hardness of melted layer decreased to 684, 536 and 436 HV$_{0.1}$. The surface hardness of cladded layer after heated for 15, 30 and 40 minutes decreased to 912, 692 and 668 HV$_{0.1}$ respectively.

The hardness of modified surface decreased when heating period increases. **Figure 3** shows the hardness properties across layer depth of melted gray cast iron and cladded grey cast iron before and after heated at 650°C with different heating time. At 650 °C temperature surface hardness of each sample decreased when the duration of heating time increased. The cladded grey cast iron was more stable at 650°C after heated for 45 minutes compare to laser melted grey cast iron. The surface hardness of cladded layer was higher than melted layer before and after heating for 15, 30 and 45 minutes due to effect of adding Mo-Cr on gray cast iron surface. Addition of Mo-Cr powder can simplify crystallization process thus improve thermal stability of cladded layer [12]. Hard phase of clad layer surface due to decreased graphite phase on cladded layer improve hardness properties and wear resistance of gray cast iron [13]. These properties are important to increase thermal stability of gray cast iron for enhanced lifetime when used at cyclic heating and cooling condition.

![Figure 3: Microhardness across layer depth of melted gray cast iron and cladded gray cast iron before and after heating at 15, 30 and 45 minutes at 650°C](image-url)

4. **Conclusion**

The laser cladding process on gray cast iron with Mo-Cr powder addition can improve surface hardness of gray cast iron. The microstructure of cladded gray iron is a matrix of pearlite with the graphite flakes. The graphite flake size of cladded layer become enlarge with increased heating time at 45 minutes. By adding alloying element of Mo-Cr in gray cast iron the hardness of cladding layer increased to 1000 HV$_{0.1}$ and decreased to 668 HV$_{0.1}$ after heating time of 45 minutes. Increase of heating time at high temperature at 650°C decreased the surface hardness properties of clad layer. The clad layer exhibits structure stability with lower hardness reduction after heating. These findings are significant to enhance thermal stability on laser clad gray cast iron with Mo-Cr powder addition.
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