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Laser cladding process to enhanced surface properties of hot press forming die: A review

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Abstract. Laser cladding is one of the advance processes in laser surface treatments. The process involved a laser beam to combines another material that has different metallurgical properties on a substrate, whereby a very thin layer of the substrate has to be melted for it to achieve metallurgical bonding with minimal dilution of added material and substrate. The resulted properties were characterized by surface topography, subsurface microstructure, hardness, and residual stresses. The objective of this paper is to review the factors that affected of cladding process to get the best cladding, suitable to enhance hot press forming die surface and subsurface. The parameter control, metallurgical bonding between coating and substrate, and effect of powder size were discussed.

Keywords: Laser Cladding; Surface Properties; Hardness; Dilution.

1. Introduction

Surface properties for many engineering applications especially in the hot press forming industry are very important to endure high temperature, wear, and friction. Physical properties include time consumption, practicality and cost are among the factor that needs to be considered for engineering materials application. The most important criteria for the selection of die material are its resistance to plastic deformation, wear, and fatigue during operation. To provide resistance to wear, fatigue, and plastic deformation, the die hardness should be as high as possible. During hot forming, the dies soften and lose their hardness quickly if the temperature on the dies exceeds the tempering temperature [1].

Implementation of surface modification, treatments, or coatings is important to reduce the lubricant requirements and increase tool life. The heating and cooling processes in laser processing depend on the processing parameter, which affects the chemical composition, microstructures, and properties of materials [2]. The laser cladding was found to deliver excellent bonding, improve hardness, have no flaws, and produce new mechanical properties and high temperature stability of the cladding layer, which improved the lifetime of die. The laser cladding process provides and enhanced the surface hardness of the materials. The clad layer is stronger, due to higher dilution of the substrate [3]. Besides that, laser cladding also an effective method to produce microstructure refinement. A study in surface treatment shown grain refinement in cobalt alloy coating when Nano particles are added [2]. This paper presents a review on surface modification using the laser cladding technique. The effect of the clad layer is used to modify the surface behavior of various materials to improved surface hardness and wear resistance. The metallurgical bonding between coating and substrate, and laser parameter control were presented.

2. Laser cladding

One of the techniques to modified or improved surface properties in advanced manufacturing is the laser cladding process. Laser cladding is one of the laser surface treatments. The laser surface treatments are based on a change of the material compositions or grain structure of the sub-surface layer, due to a heating and cooling cycle by a laser source [4]. The advantages of implement laser cladding are improved grain size, increased hardness, minimal dilution, and produce new surface properties. Laser cladding uses a laser heat source to produce the desired clad layer during laser processing. The deposited material can be transferred to the substrate by several methods such as pre-placed powder, powder injection, paste powder on the substrate, or wire feeding as shown in Figure 1. Laser cladding with powder injection is proven to be the most effective method for the produced clad layer. During the cladding process, the laser beam melts the powder particles and produces thin layer on the substrate [5]. Laser cladding can be used as a safe technology to repair die surfaces, especially on critical contact surfaces. Laser cladding also increases tool life and saves manufacturing costs.

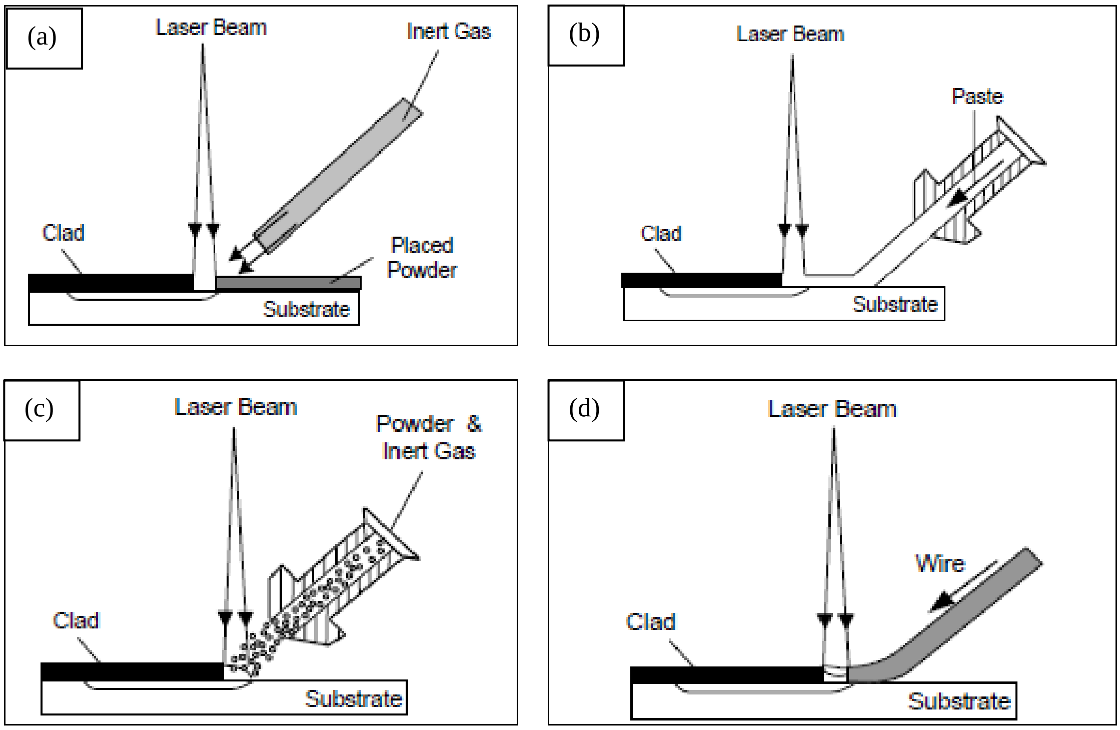

Figure 1. Different methods of laser cladding: (a) placed powder laser cladding, (b) paste laser cladding, (c) powder injection laser cladding and (d) wire feeding laser cladding. [5]

3. Effects of laser parameters on cladding properties

Laser processing parameters affect the variation of hardness, microstructure and geometry of the clad layer. It is measured by metallurgical characterization and microhardness testing [6]**. I**mportant features in laser cladding are clad height and dilution. The parameters used to control the setting are laser power (P), velocity of moving laser beam (v), diameter of the laser beam (D), and preheating temperature of the substrate (T) [7]. Processing parameters are one of the methods to improve the cladding quality is using a different substrate, powder, and type of laser will gain a different parameter. In order words, the different experimental parameters will led to different microstructure [8]. Combining appropriate processing parameters such as peak power, overlapping factor, and pulse duration during the laser cladding process using a pulse laser is crucial to produce independent and uniform results. Other effects such as overlapping factors for the width and depth layer can be seen throughout the molten pool [9]. The selection of proper processing parameters is required to avoid high residual stress concentration [10]. Also, this parameter can help determine the clad profile, dilution of the cladding metal, a fusion between layer, homogeneity, and surface finish defect such as porosity, crack, etc. [11]. The clad characteristics such as height and width can be designed to get optimum metallurgical characteristics with maintain its maximum deposition rate [12]. The hardness of clad layer is much influence by the amount and type of powder used, and also involves the wear resistance of its clad layer which affects the hardness and wear resistance [13]. In pulse energy lasers, the formations of clad layer are mostly influenced by pulse energy itself. Pulse duration increased laser pulse and overlap are factors that affect the surface roughness of clad layer. It has been observed that a rougher surface is obtained with a large laser spot increment and overlap with shorter pulse duration. Smoother surface can be obtained in using small laser spot increment and overlap with the use of longer pulse duration [14]. Many researchers do research on preheating the substrate before cladding process. This is because many of them find that this is the most effective method that can reduce the cooling rate significantly. Without using this method first, the clad layer will most probably produce crack in the end result [15].

4. Metallurgical bonding and dilution in cladding

Other important factors in the performance of laser cladding are the dilution rate of single-track cladding. The dilution rate is large and a large amount of substrate material will be mixed to the coating thus affecting the properties of the coating. But, when a small dilution rate is applied, a good metallurgical bonding cannot be achieved in the interface between the clad layer and substrate. Approximately, the appropriate dilution rate of the laser cladding layer should be around 10% to 25% [15]. During the laser cladding process, the temperature in the middle of a single track is higher than on both sides of the track. Thus, the thickness in the middle of the layer is greater than both sides of the layer, as shown in Figure 2.

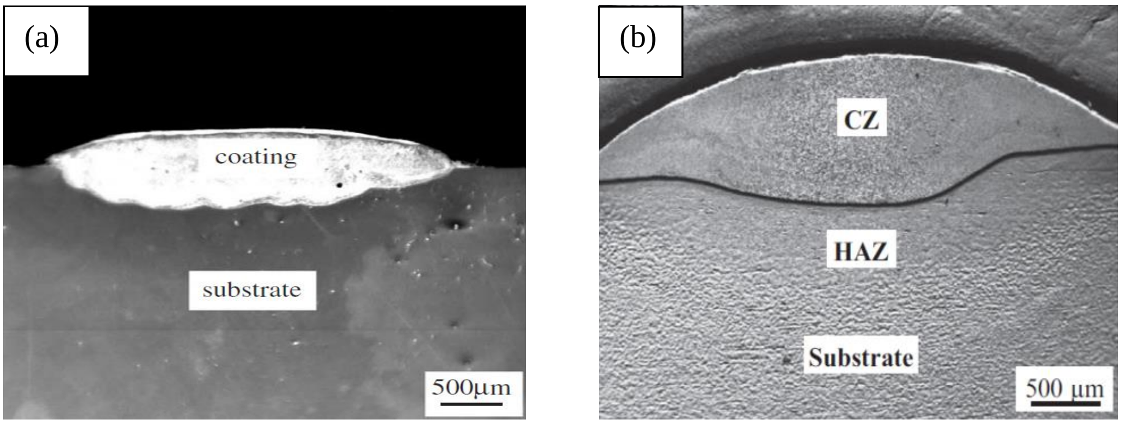

Figure 2. SEM micrograph (a) and (b) showing cross section morphology of one coating track. [10, 11].

The morphology of the cross-section layer can be divided into three regions, clad zone (CZ), heat affected zone of the substrate (HAZ) and the substrate [16]. The diluted zone reduces surface hardness and expandability between the clad layer and the substrate, which is expected to strengthen the adhesion of the layer to the substrate. The clad layer is free from pores and cracks, with low dilution, homogeneous microstructure and good metallurgical bond to the interface region [11].

5. Hardness properties

Laser claddings are proven to increase surface hardness up to 4 times of the substrate due to secondary carbides, grain refinement, and hard non-equilibrium microstructure formation. During cladding process, the molten pool rapidly solidifies and produces a fine grain refinement [17]. From the previous study, the main reasons for the increase in microhardness in the hardness of the AISI 304 stainless steel/ Al_3O_3 composite coating on AISI 1045 steel are due to the strength solution effect of the Al element and also due to presence of martensite in the heat affected zone [18]. The increased surface hardness of the clad surface is due to the presence of martensite and fine unsaturated carbides in the microstructure [19]. The high hardness value of the substrate near the intermixed area is due to the rapid melting and solidification of steel resulting in martensite in these steels [20]. Reducing the particle size of powder will increase the hardness of the copper matrix composite by 47% compared to pure copper [21]. Figure 3 shows, various microhardness distribution on the cross-section of the laser cladding layer. Surface hardness increase in clad layer and rapidly decrease through HAZ to the substrate and constant low hardness in the base substrate. Higher hardness in clad layer due to rapid heating and cooling, where grain sizes were improved. While delay solidification in HAZ causes latent heat and produce low hardness in HAZ.

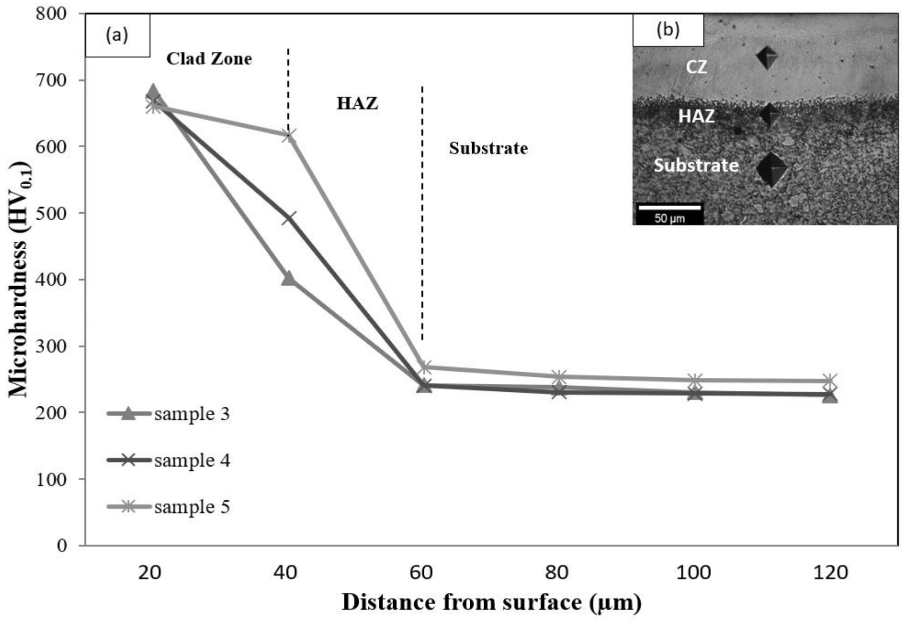

Figure 3. Various microhardness distribution curves on the cross section of the laser cladding layer. [22]

6. Effects of powder sizes on cladding morphology

Different sizes and types of powder give some effect on the microstructure of the clad layer. Table 1 shows the type of various powder and effect on claddings morphology. The main methods in the preparation of powder are to use high-energy ball milling technique. Powder size, morphology, uniformity as well as microstructure and properties of cladding property mainly been influenced by the milling time in the preparation of the powder itself [23].

Table 1. Type of powders used in various laser cladding and their effect on clad morphology.

Reference	Type of powder	Effect
[24]	Chromium (Cr)	Good cladding layer without defects (cracking and porosity), improve hardness and corrosion resistance
[14]	Tungsten (WC)	Improve wear resistance and decreased porosity in the coating
[25]	Titanium (Ti)	Microstructure becomes refine and uniform
[13]	Copper, Molybdenum, Silicon (Cu, Mo, Si)	Improve hardness and wear resistance

The magnified cross-sectional SEM morphologies of laser cladding coatings near the top surface after polishing with powders pre-milled with different time shown in Figure 4**,** the figure shows some effect on the microstructure of the coating. The powder was fabricated with a pre-mill for 1 hour shows course cellular and uniaxial phase. For the powder that pre-mill for 12 hours, present the dendrites as well as relatively slander cellular and uniaxial microstructure. The result from sample show that similar structure gain from pre-milled powder for 24 hours to that 12 hours but with smaller grain sizes.

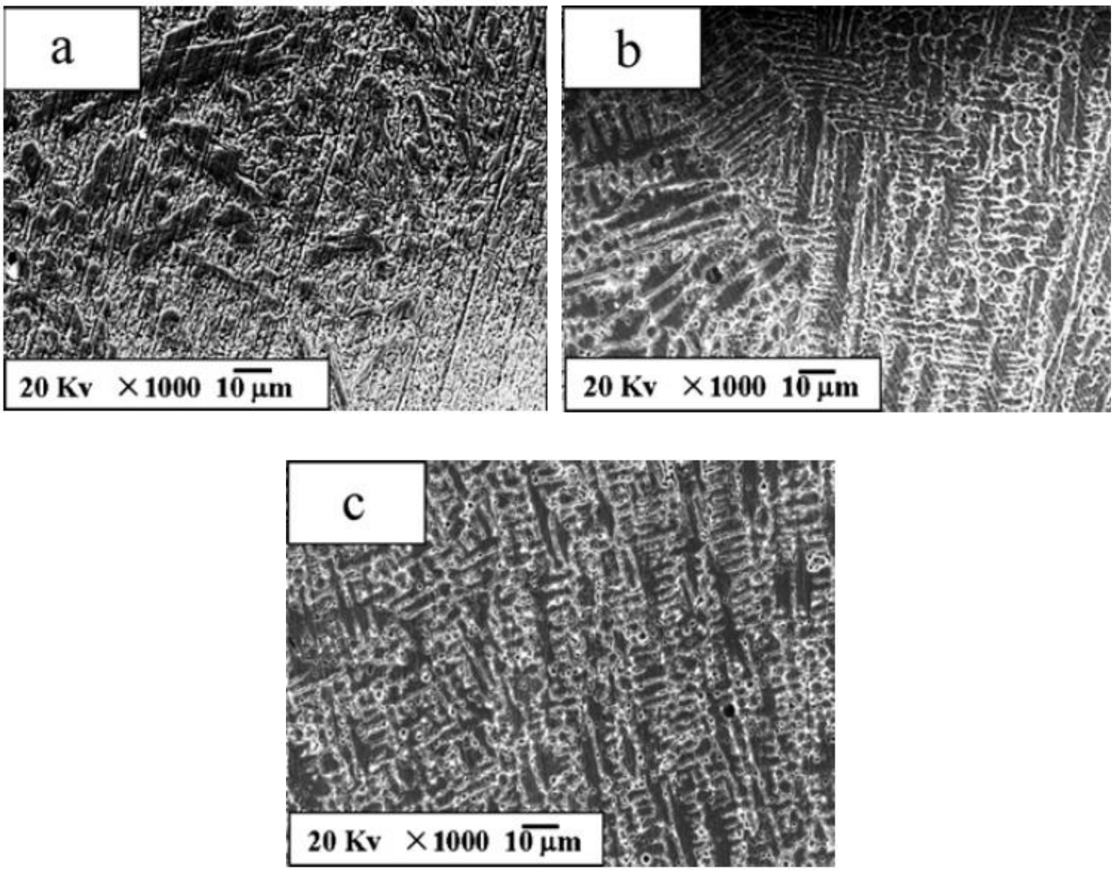

Figure 4. The magnified cross-sectional SEM morphologies of laser cladding coatings near the top surface after polishing with powders pre-milled for (a) 1 h, (b) 12 h and (c) 24 h [23].

It can be concluded that different size of the powder to make the coating are composed of grain with different shape and size. It shows that different size of the powder produced clad layer with consisting of grain with different shape and size.

7. Conclusions

The study of various works in the laser cladding process indicates that parameter control, substrate preheating, sizes of the powder, type of powder and dilution rate affect the metallurgical bonding, wear-resistance and hardness of the coating layer. Therefore, to enhance surface properties of the HPF die material, the above factors should be emphasized. Using suitable parameters can produce hard layer with excellent metallurgical bonding to the substrate material, uniform composition and preferable coating thickness.

Acknowledgments

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