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# Laser Cladding Process: An Exhaustive Review

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**Abstract: Many thermal surface treatments are available to increase the quality of metal parts, such as WR and CR, autogenous welding and many more heat treatment methods. Poor bonding, porosity, thermal distortion, incomplete penetration and other issues can develop depending on the technology used. One way for overcoming these issues is laser cladding. Laser cladding is a deliberate technology. it may provide superior qualities in terms of purity, unvaried, solidity, fuse and inclusions in comparison to other difficult processes. The applicability and requirements of the LCP in industries are discussed in this review study. In today's market, it's become a necessary surface modification technique and it's still gaining appeal.**

**Abbreviations: LASER, Light Amplification by Stimulated Emissivity of Radiation; TGO, Thermal Grown Oxide; LC, Laser Cladding; LCP, Laser Cladding Process; PFR, Powder Feed Rate; WFR, Wire Feed Rate; ICE, Internal Combustion of Engine; FMCG, Fast Moving Consumer Goods; MMC, Metal Matrix Composite; LP, Laser Power; SS, Scanning Speed; SD, Laser Spot Diameter; PT, Pre-place powder thickness; SVM, Support Vector Machine; SEM, Scanning Electron Microscope; CoF, Friction Coefficient; MTOR, Multi Track Overlapping Ratio; HS, High Speed; WR, Wear Resistance; LSV, Laser Scanning Velocity; RCS, Residual Compressive Stress; US, Ultra Sonic;**

***Keywords* —*Laser, cladding, tribological, amplification, emission, dilution***

## I. INTRODUCTION

Since 1960, when Theodore Maiman created the first functional laser, the laser business has grown at a rate of around 10%-20% per year [1,2]. The expansion is fueled by the rising use of laser light, which is a type of optical energy [3]. Lasers have been used over the years, in a wide range of applications, including mensuration, camera work, process of raw materials, drugs, communications, and voltaic [3,4]. During processing, the interaction of laser radiation with materials causes structural vibrations in the substance. The resonate is recognized as warm, which may be powerful sufficient to melt the substance, converting thermal energy by converting optical light [4]. It is created by stimulating an energy source (light, electricity, heat etc.) and an active medium (solid, liquid or gas). This energy is in the form of light is converted to thermal energy in manufacturing by concentrating ray of light with a sight set up to the desired spot shape and volume.

## II. LASER CLADDING PROCESS

The creation of lasting coatings on material surfaces is one of the most important concerns in modern engineering. Not only does laser technology offer a one-of-a-kind means to modify the surface of materials and obtain desired surface features, such as transformation hardening, alloying and cladding. These are all tried and true methods. Laser cladding is one of the procedures utilized in the sector (LC). Figure 1 depicts the LC process employing off-axis powder injection material. Both of these variables are critical in obtaining high-quality clad. An intersecting or at an angle to axis of nozzle injects the metallic powder into the molten pool. The cladding material is melted over the substrate or base metal by a high-power laser beam.

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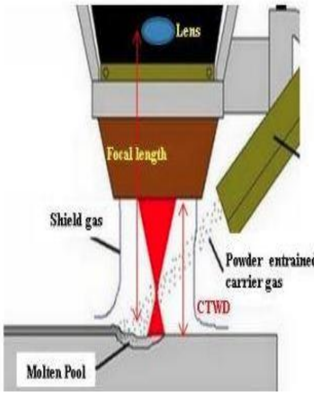


**Fig. 1 The LCP is depicted in this diagram [9]**

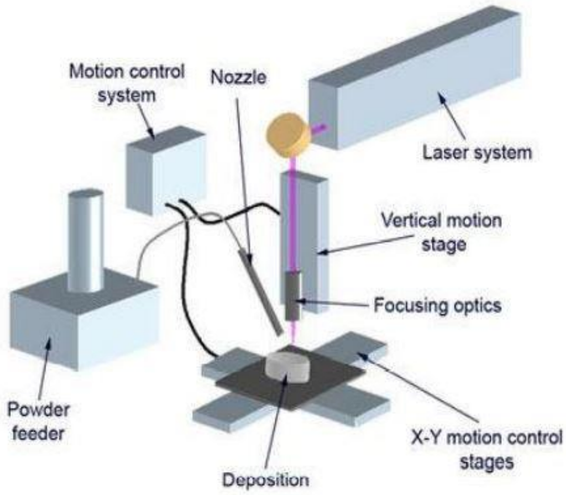


**Fig. 2 Schematic of the LC System's Equipment [8]**

Different qualities are frequently required at different areas on items, according to research. Wear and corrosion resistance, for example, is only required on the product's surface. Laser cladding is an advanced coating process that results in a metallic link between base metal and the clad material [10].

## III. APPLICATION

Restoration and refurbishing of great value components (Tools, Turbine blades, Gas turbine and ICE) [12,13] is a key use of LCP. Furthermore, Direct material deposition using a laser has a number of applications, including Coatings with functional properties, deposit for repairs quick drawing and analysis alterations and create ferrous/nonferrous sections. Figure 4 depicts the dimensional properties of a single clad bead's average cross section. Dimensions physical qualities are considered part of the cladding process' outcomes.

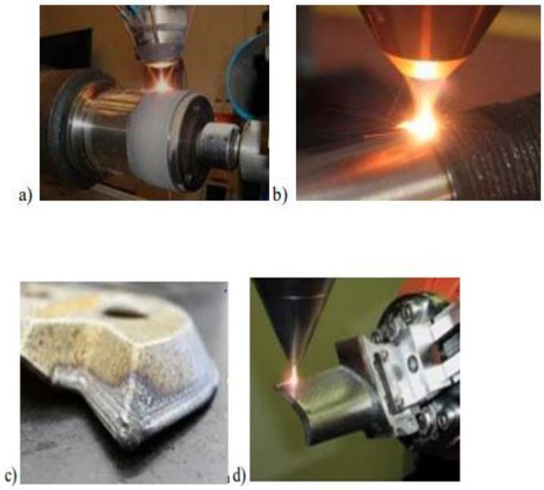


**Fig. 3 A Laser clad area application [12, 13]**

## IV. CLADDING PROCESS PARAMETERS

Features and some of the desirable outputs are typically observed. The impact of laser input variables on various output properties is studied further.

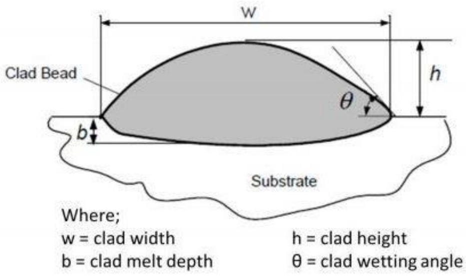


**Fig. 4 A single clad bead's average cross section [6]**

Ray Energy

The quantity of heat produced by the ray is a critical aspect in LCP.

Traverse speed

When all other independent parameters are held constant, material supply per unit declines as traversal speed raise, resulting lowering clad size.

Carrier (Defensive) gas

The carrier gas assists to prevent the melt pool from oxidation on a local level. Ar, N, He are the gases used as carrier gases in LCP. Ar is less expensive.

PFR and WFR

The clad in LCP either in powder or wire. Furthermore, it supplies either coaxially or laterally by a specific feeding nozzle.

Preheating

In some circumstances, preheating materials before LCP. It's all relies on the materials and how easy they are to weld. Cracks, delamination, deformation, and porosity could all result from this residual stress. The rate of

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cooling during the process is slowed by preheating.

Stand-off Distance (mm), LSD (mm), Laser Torch Angle (degree), Wire Diameter (mm), Nozzle type, Clad size (height and width in mm), Wire material density (g/cm3), Laser beam mode parameters also affect the quality of cladding materials in LCP.

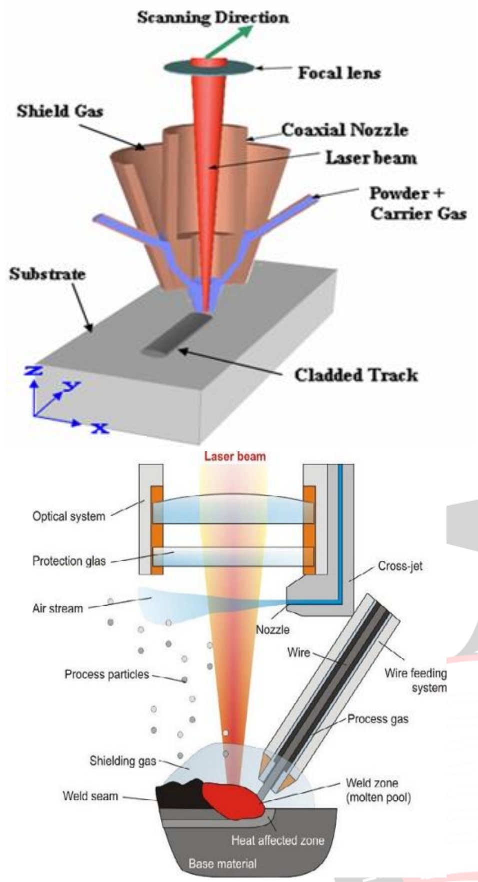


**Fig. 5 Feeding strategies: coaxial (left) and lateral (right) [14]**

## V. Review On Laser Cladding Process

Piera Alvarez et. al. (2018) has worked and reported that the most productive process parameters were determined to be 13 mm/s scanning speed, 2500 W power, 30% overrun, and a 25 gram/minute PFR. In LCP, the ray energy must be between 3000 Watt to 2000 Watt to control and avoid overheating component [15].

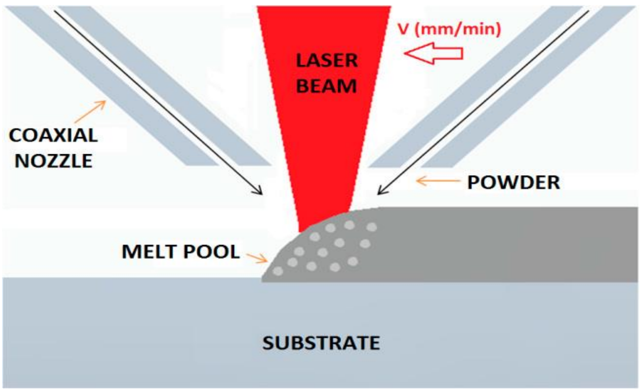


**Fig. 6 The coaxial laser cladding system is depicted schematically [15]**

Yu. A. Chivel (2018) has work on using conical laser beams. The initial circular ray energy is split in more than one round rays with a controlled laser power distribution between them. For efficient heating, the round rays that strikes distinct portions of the clad materials. Substrate heating minimizes residual strains. Melt contact creation requires a certain power density. The thermal process is optimised by spatially and segregated the surface part, which minimises energy consumption and enhances cladding accuracy and quality [16].

L. Reddy et al. (2018). Laser cladding was used to deposit the Fe-Cr-B alloy Nano Steel SHS 1770 on low alloy steel base metal in this investigation. The goal was creating a math replica to calculating the rectification variables required for create. It is possible to draw the following conclusions: 1. There are two parts to powder deposition efficiency. The 1st is independent variable and experiential estimated. The 2nd is determined by the ray energy to PFR ratio. 2. Outgassing is demonstrated to be the cause of porosity; hence it is unaffected by processing conditions. For a c/s of pulverize atom, a method for predicting porosity inside powders has been developed. 3. The models have been validated by creating overrunning clad and comparing their computed properties to the model's predictions [17].

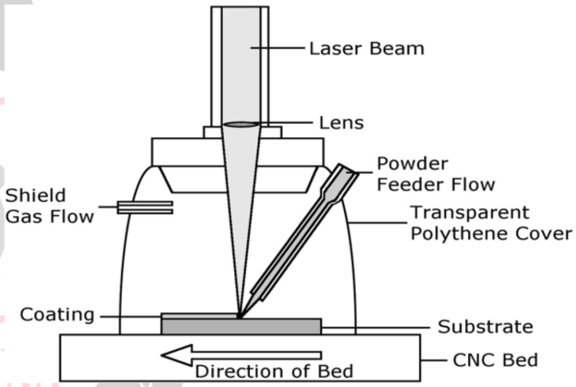


**Fig. 7 A schematic of the front-fed powder setup [17]**

N. Tamanna et al. (2018) have research is to figure out what causes extensible residuary pressure to occur and reduce it in additive material when employing different base metals and additive materials. A 1-D methodical replica was used to calculate extensible residuary pressure. The pressure produces in dissimilar additive and base metal with variable foreheat ambient of the substrate was calculated and compared using a methodical model. On the surface of H13 tool steel base metal, four cladding materials were used: $TiO_2$, TiC, $ZrO_2$, and $Al_2O_3$. Highest residuary pressure was formed in the TiC clad below the substrate's foreheat ambient of 900 K. Greater than 900 K, the largest residuary pressure was formed in $ZrO_2$ additive. $Al_2O_3$ clad was determined to have the lowest residuary pressure. The formation of residuary pressure was shown to be influenced by roasting exertions and modulus of elasticity. The $Al_2O_3$ clad had the smallest roasting exertions mismatch. The clad's residuary pressure can be reduced by reducing roasting exertions mismatch [18].

Alexandra Pascua et al. (2019) have work on Laser


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cladding and the reconditioning process / Laser cladding is the finest technique for reconditioning damaged titanium alloy aero plane engine blades. Laser processing technology has become widely used in industries, particularly in the industries of ray energy and pulverize feedstock reconditioning. A strong attachment to the substrate with no obvious material delimitation. The additive layer is thick, devoid of inadequacy, and has a microstructure that is consistent. Economically efficient industrial engineering methods compel the recycling of metal parts to the greatest extent possible. Recycling worn parts/components can save money in the automotive and aerospace industries, however the best option to lessen environmental effect is to repair worn components, which uses less energy than refabricating the original component [19].

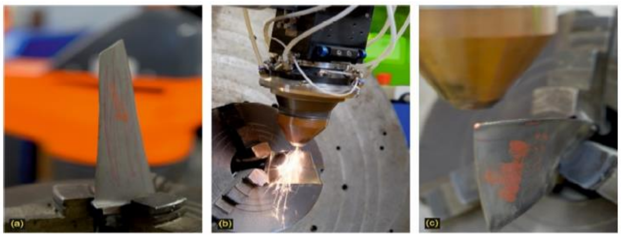


**Fig. 8 Jet blade experimental repair [19]**

Jurandir Marcos S et al. (2019) have work on the tribological performance of a co-axial powder nozzle / Ni-Cr-B-Si alloy added by LCP is assessed. The selection of deposition parameters is a challenging task. A fibre laser source with a coaxial powder nozzle was used to deposit Ni-Cr-B-Si coatings on a Low Carbon Steel base metal in this study. The testing included microstructure, micro hardness, and abrasive wear. Coatings with good surface adherence were discovered. Micro hardness was 10% greater in coatings with higher chromium carbide content and phase size. There was a 10% difference in volumetric loss and wear coefficient between the coatings. Varying heat gradients resulted in different dilution levels of coatings, which affected their abrasion resistance. Coatings with lower cooling crack density and a higher volumetric fraction of carbides had improved tribological performance, which both inhibited wear micro mechanism action [20].

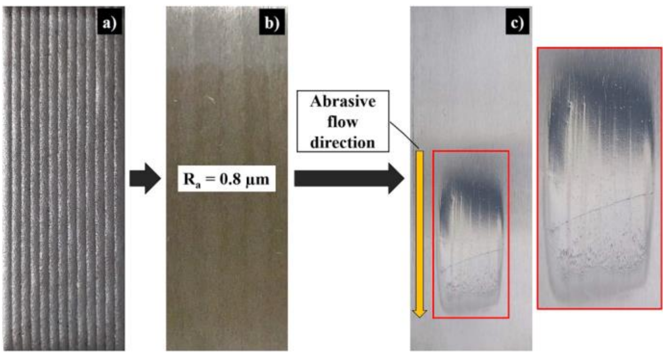


**Fig. 9. (a) Coated, (b) Grinded and (c) After Tribological Test [20]**

Jiaxin Zhao et al. (2019) In this study, a transient in three dimensions to imitate the different LCP with T15 pulverize and T15 or CeO2 mixed pulverize on 42CrMo, a multicomponent multiphase model was developed. SEM was used to examine the nanostructure of the additive layer, which was examined using the solidification parameters acquired from the computational model. Planar and cellular grains make up the transition zone. The grain morphology was linked to the solidification properties determined from the numerical model [21]. A comprehensive numerical model was developed that took into account ray energy input, metal addition, vapor movement, convey substance and stage transition. The profiles produced from the mathematical estimation were in fine accord with the additive layer contour acquired via unique path additive trials shy of action settings. The mean deviations of the clad dimensional size and mixture rate for T15 cladding samples are 3.2 percent, 16.2 percent, 12.8 percent, and 6.5 percent, respectively [21].

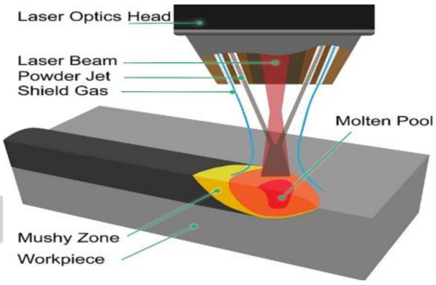


**Fig. 10 Laser cladding process [21]**

Tao Chen et al. (2019) Choosing optimum procedure variables for LCP of large grade covering employing microparticle TiC ceramic pulverize as the initial metal. The coating quality attributes were especially important for PT, SD, and LP. The ceramic coatings' optimal process parameters were discovered. The SVM model accurately predicted the quality attributes of ceramic coatings [22].

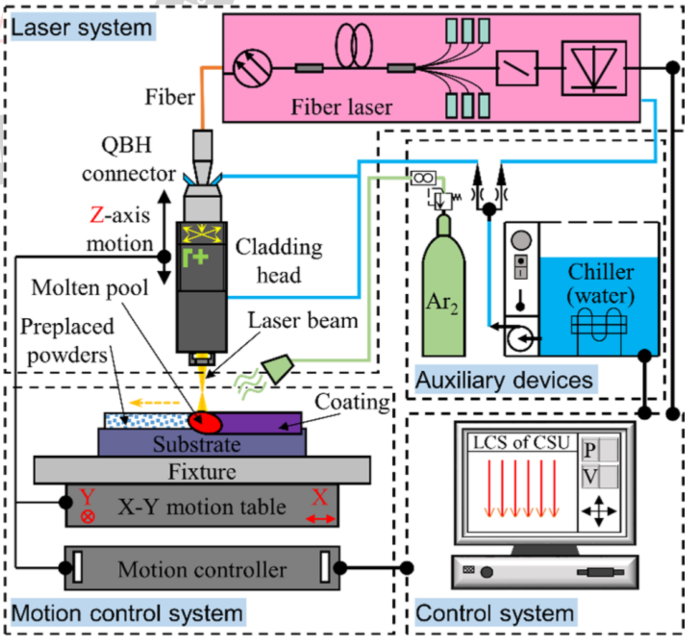


**Fig. 11 Laser Cladding System [22]**

Qing-Long Xu et al. (2020) LCP / This research proposes an auspicious latest union tunic based on the CuAlNiCrFe elevated destruction compound. The fore-decomposition situation of the typical thermally sprinkle MCrAlY union


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tunic and the CuAlNiCrFe elevated destruction compound union tunic added utilizing high-speed LCP were compared. The results showed that a CuAlNiCrFe elevated destruction compound bond coat added using HS LCP can complete fore-decomposition quick and shape a continuous Al2O3 TGO, beginning decomposition period and prevents the emergence of other base metal and atomic number. Similar to the thermal spray procedure, a HS LCP was employed to generate a high entropy alloy bond coat with metallurgical bonding with Ni based super alloys substrate [23].

Y. Javid (2020). LCP of WC on Inconel 718 is explored in this work. The desirability technique is utilized to generate an additive film of suitable shape with little mixture, sponginess, fracture and an extremely effective operation using response surface methodology (RSM). Practical are conducted to validate models and findings show that laser power is the most important element impacting dilution and clad width, while scanning velocity has a significant impact on porosity and cracks. Large areas of laser cladding must be done in numerous passes. As a result, there must be some overlap between adjacent passes. Pull off tests (Adhesion Test) were performed to ensure a good connection between the substrate and the coating [24].

**Fig. 12 Specimens [24]**

N. Jayaprakash and Che-Hua Yang (2020). During continuous sliding, however, it exhibits weak tribological characteristics. Two different alloy powders, NiCrFeMoNb and FeCrMoVC, were added on nickel based superalloys in this work. The hardness, phase development, and microstructure of the generated layers were also studied. Two different compounds pulverize, NiCrFeMoNb and FeCrMoVC, were added on nickel based super alloys in this investigation. The hardness, phase development and microstructure of the generated layers were also studied. Laser addition showed a homogenous shape with enhanced rigidity, according to the results. The goal of this study was to investigate the structural changes and wear resistance of NiCrFeMoNb and FeCrMoVC produced layers on nickel-based superalloys. The following conclusions were formed based on the findings. The surface of NiCrFeMoNb laser cladding has a maximum of - nickel phase, whereas FeCrMoVC cladding exhibits martensitic phase. Cross-sectional view of both cladding samples with free of defects. Cladding region shows the various microstructures due to constitutional undercooling. Due of the finer microstructure, the hardness of FeCrMoVC coating increased the strength over NiCrFeMoNb laser cladding. According to the Hall–Petch connection, grain size has a significant impact on hardness, as hardness falls as grain particle size increases. The CoF and wear rate of FeCrMoVC cladding are reduced than substrate and NiCrFeMoNb cladding due to tribo oxidation layer. Besides, formed oxide layers can protect the specimen surfaces from the unexpected damages. The wear behavior of substrate and cladding surface reveals that metal removal is a process of abrasion, adhesion and oxidative wear. The VC carbides in FeCrMoVC cladding possesses good wear resistance than base material and NiCrFeMoNb cladding, while attributing those characteristics in morphology and hardness of VC carbides [25].

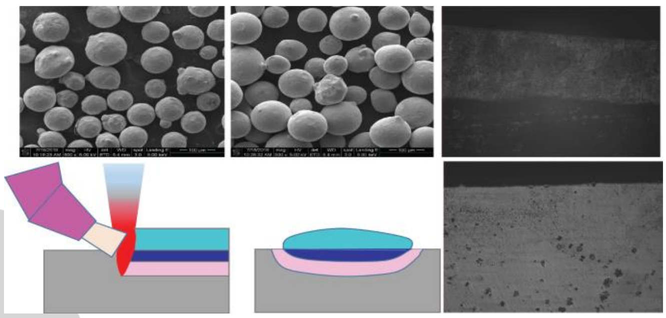

**Fig. 13 SEM images of alloy powders; NiCrFeMoNb (a) FeCrMoVC (b) schematic picture of laser cladding process, outline showing the geometrical parameters of laser clad; width, height and depth (c) Cross sectional optical micrograph of cladding; NiCrFeMoNb (d), FeCrMoVC (e) [25]**

Corbin M. et al (2021). LC is a maintenance technique that involves depositing 0.05 mm to 2 mm metal of material on a metal substrate without crack, small porosity, and excellent qualities using a HPDL. A 4 kW HPDL is employed in this study to add tracks of aluminium alloy 6061 powder on a 6061-T6511 substrate using inclined powder injection. The parameters were changed to find the best processing window for achieving a successful clad. The parameters were connected with geometrical properties, and the trends were discussed. The mechanical characteristics of the clad were investigated using microhardness testing in both the as added and precipitation states. The hardness variations investigated using TEM [26].

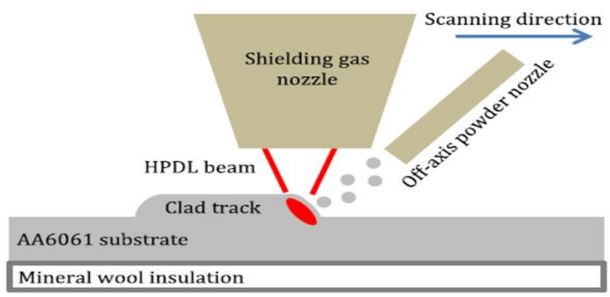


**Fig. 14 Laser Cladding Schematic [26]**

Minjie Song et al. (2021). To evaluate the efficiency of fatigue life enhancement, the temperature field and residual stress field are explored under various LP, LSV, clad size, LC patterns, and LC angles. The M-integral

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approach is used to determine stress intensity factors, and the Paris equation is used to check fatigue life. The results demonstrate that laser cladding samples with a LP of 1400 W and a LSV of 10 mm/s had the best crack resistance. The fatigue life of the sample with a 50 mm cladding covering is 2.93 times that of the untreated sample. The linear pattern performs better than other designs in terms of fracture resistance, and the best crack resistance is produced when the cladding angle of the linear pattern is 0. The results show that samples treated with laser cladding have a considerably longer fatigue life than untreated samples, owing to the residual compressive stress created by the laser cladding technique. The fatigue life increased by increasing the LP or decreasing LSV. LC parameters, LC patterns and LC angles can all effect sample fatigue life [27].

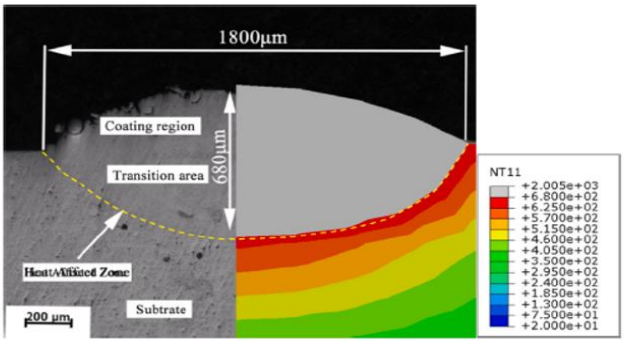


**Fig. 15 LCP [27]**

Honghao Ge et al. (2021). The fatigue life of the sample with a 50 mm cladding covering is 2.93 times the original life. Straight arrangement performs good than other designs in terms of fracture resistance and fracture opposition is produced if angle of the linear pattern is 0. The samples treated with laser cladding have a considerably longer fatigue life than untreated samples, owing to the residual compressive stress created by the laser cladding technique. The debility life of laser-treated samples can be increasing the LP or decreasing the LSV. Laser parameters, LC patterns, and LASER angles can all effect sample fatigue life. Both mixing steps have a substantial impact composition of adding material. During heterogeneous chromium composition distribution was detected in both experimental and simulated results due to insufficient penetration [28].

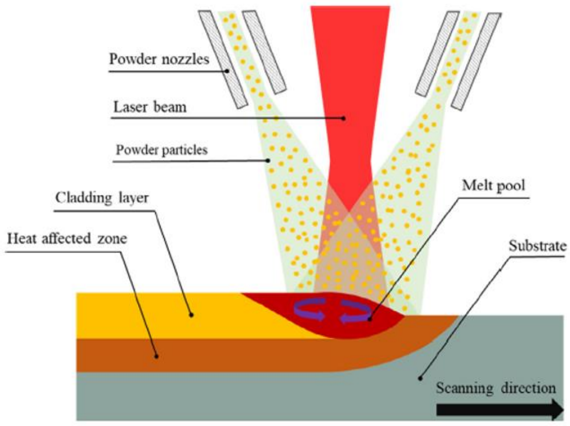


**Fig. 16 LC system [28]**

Lida Zhu et al. (2021). Metal component formation has benefited from laser cladding. However, the challenges that come with it, such as interior microstructural flaws and poor mechanical qualities, need to be looked at more. To increase the performance of the produced pieces, laser cladding technology was combined with ultrasound in this investigation. according to During the metal solidification process, the combined action of acoustic streaming and acoustic cavitation, the vibration parameter has an effect on the degree of undercooling and nucleation rate of molten metals. investigated. The results of the experiments reveal that the grain size obtained using ultrasonic technology is significantly smaller than that acquired using conventional methods. The vibration was finer than that obtained under standard laser cladding conditions. When the amplitude was at its maximum, The average grain size was 0.522 times that of non-vibration at 25 meters. The precipitate's phase structure. The chemical makeup of the water also altered dramatically. In addition, the effects of high-frequency vibration on the human body have been studied. Contrast tests were used to examine the mechanical properties of the cladding layer. The findings show that using high-frequency vibration to reduce porosity while boosting microhardness is a good idea and abrasion resistance The friction coefficient was 0.628 times that without ultrasound and 0.709 times that with ultrasound. When the amplitude was 25 m, the processing time was three times that of conventional processing [29].

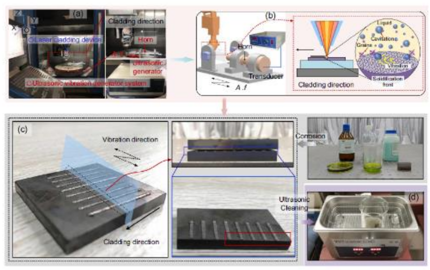

**Fig. 17 US vibration LC [29]**

Dariusz Bartkowski et al. (2021). The study of properties of Fe/WC MMC plating generated with various LP values and powder feeding rates is presented in this research. The LC method was used to create coatings using a Yb: YAG disc laser. The LP employed were 600 W, 700 W, and 800 W. For all plating, the LSV of the laser beam was equivalent to 600 mm/min. The SD was 1.64 mm. There were two PFR used: 6.25 g/min and 12.50 gram/minute. X-ray diffraction analysis and Energy Dispersive X-ray microanalysis performed in this study. CR was looked upon as well. A different sort of secondary carbide, bar shaped or plate-shaped, was detected in coatings created with an increased PFR. The existence of WC, $W_2C$ phases, as well as $M_{23}C_6$ and (Fe, W)$_3$C complex phases, was revealed by X-ray diffraction and Energy Dispersive X-ray microanalysis examination of the composite Fe/WC plating. On the basis of the microstructures acquired, the mechanism of composite coating generation and growth

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was outlined. Coatings generated at a PFR of 12.50 gram/minute had the maximum microhardness and CR [30].

Wuyan Yuan et al. (2021). HS LCP increase coating preparation broad applications for LC. Low speed LC and HS LCP were used to deposit Ni45 particles on steel substrates in this investigation. The standard and HS LC Ni45 alloy plating compared in terms of material adding efficiency, surface contour, c/s structure, wear and CR qualities. The HS LCP plating was significantly thinner than the standard LC plating, as can be seen. HS LC achieved a process speed of 76.86 meter/minute and a process efficiency of 156.79 cm2/minute, compared to regular LC. The two types of coatings have similar microstructures, but the microstructure in HS LC was mini and heavy, and the columnar crystal spacing was narrower, only approximately 6 m. The cooling rate of typical LC plating was found to be lower than that of HS LC, and the cooling rate rose as the process speed increased. The typical LC coating's cross-section microhardness was reasonably homogeneous around 337 HV0.2, but the microhardness of the HS LC surface increased to around 543 HV0.2. Furthermore, HS LC coatings outperformed standard laser cladded coatings in terms of wear and CR. The wear and CR of the cladded coatings improved as the cladding speed increased [31].

Liaoyuan Chen et al. (2021). To repair the surface defects of spline shaft and improve wear resistance, the bristly TiC strengthen Nickel based mixed coatings created on the spline shaft surface by LC with six types of precursors containing Nickel45, bristly TiC and narrow TiN powder. The impact of ceramic content and TiN adding on the adjustable, polymeric and unemotional characteristics was investigated. The optimum plating was ground to acquire the final exterior using additive/ subtractive hybrid manufacturing technology, indicating that the bristly TiC strengthen plating used to repair damaged [32].

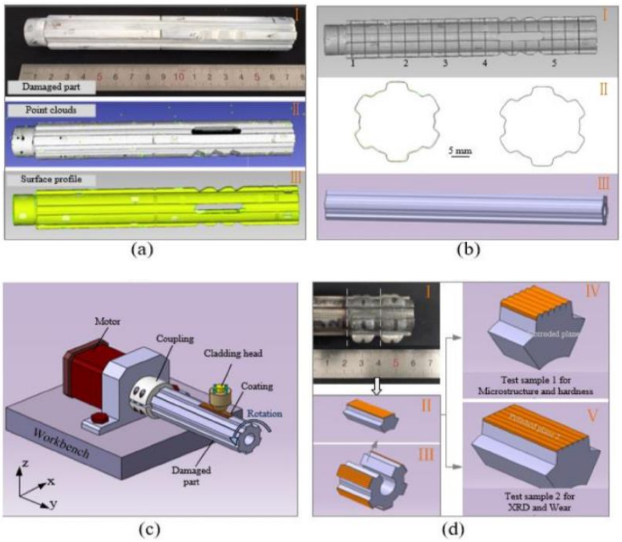


**Fig. 18 (a) Damage part, (b) 3D shape damage part, (c) LCP, (d) Hamming of restore zone [32]**

## VI. Applications

As per review of research papers, the uses of Laser Cladding technology have a number of applications, particularly in the Automotive, FMCG, Medical, Manufacturing industry etc. It is usually used to refurbishment, create and repair components like tools, shafts, blades, turbines, drilling tools etc. The aim of implementing laser cladding technology is repair welding, surface cladding, and part manufacturing. The popular tools and components made using laser cladding technology are i. Drilling Tools, ii. Agricultural Machinery, iii. Hydraulic Cylinders iv. Heat Exchangers, v. Bearing Journals, vi. Shaft (Turbo, Propeller), vii. Cast Iron Parts, viii. Exhaust Valves, ix. Rotors, x. Turbine and xi. Piston Rods.

## VII. Conclusions

As per given research papers, LCP give significant development in mechanical characteristics of materials. LCP increase the exterior grade of metal components, such as wear and CR. By using laser cladding process, we get our required materials at very low cost. We made MMC materials by using LCP. The aim of this study is to investigate the structural changes and WR of layers generated on a substrate. Laser cladding process fulfill the application and recent requirement of modern industries. The size and the residual compressive stress can both rise as laser power is increased. The increase in laser scanning velocity has a negative impact. The residual compressive stress rises as laser power rises.

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