Recent Developments in Cladding Process – A Review

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Abstract

Cladding is the bonding of dissimilar metals, it is often achieved by extruding two metals through a die and pressing or rolling sheets together under high pressure and also repairs the surface of various components, in order to improve resistance to wear, corrosion, erosion and oxidation. The present review is focused on comparison of different cladding processes, like roll bonding, explosive cladding, plasma cladding and laser cladding. Different types of cladding are discussed and various applications of high-performance cladding are discussed in terms of various substrate and coating materials. The various aspects and advantages of each application are highlighted to show the compatibility of cladding process for material-processing applications.
Keywords: Laser Cladding, Plasma Cladding, Roll Bonding

NOMENCLATURE

- PTA - Plasma Transferred Arc.
- TIG - Tungsten Inert Gas.
- XRD - X-Ray Diffraction.
- SEM- Scanning Electron Microscopy.
- OM - Optical Microscopy.
- UFG - Ultrafine Grained.
- ARB - Accumulative Roll Bonding.

I. INTRODUCTION

The past decade has witnessed the emergence of new manufacturing technologies, where manufacturing time for parts of virtually any complexity is measured in hours, instead of days, weeks or months. This is when Rapid Prototyping (RP) was conceived. Many RP technologies are available in the marketplace; however, these technologies utilize plastic (or similar) material to create parts and, thus, many parts are non–functional. Sterolithography Apparatus was the first commercially available RP system that successfully produced physical prototypes. It enabled the visualization of components produced directly from a CAD model by polymer curing with lasers. Laser–based RP systems have been introduced as a means of creating functional, metal prototypes with near–net shape geometries and development efforts are being conducted in their low productivity and inability to consistently regulate part research centers throughout the world. The drawbacks to these systems are quality in terms of mechanical properties and geometry. To overcome these drawbacks, process control strategies have been utilized. This paper provides an overview of this body of research on cladding recent developments.

II. CLADDING

Cladding is the bonding together of dissimilar metals. Cladding refers to the metallurgical process of coating a metal onto another metal under high temperature and pressure so as to protect the inner metal from corrosion. It is often achieved by extruding two metals through a die as well as pressing or rolling sheets together under high pressure. Cladding may be done with different methods such as; Laser cladding, Plasma cladding, Roll bonding and Explosive cladding.

A. Laser Cladding

Laser cladding is a method of depositing material by which a powdered or wire feedstock material is melted and consolidated by use of laser in order to coat part of a substrate. Laser cladding uses the high energy density generated by a laser beam to form a molten pool in a base material for metallurgically bonding with a filler material using a diffusion type of weld. Laser Cladding is a weld build-up process and a complementing coating technology to thermal spray. It is increasingly used instead of PTA (Plasma Transferred Arc) welding and easily outperforms conventional welding methods like TIG (Tungsten Inert Gas) for advanced weld repair applications.

B. Process Description

In laser cladding, the laser beam is defocused on the work piece with a selected spot size. The powder coating material is carried by an inert gas through a powder nozzle into the melt pool. The laser optics and powder nozzle are moved across the work piece surface to deposit single tracks, complete layers or even high-volume build-ups.

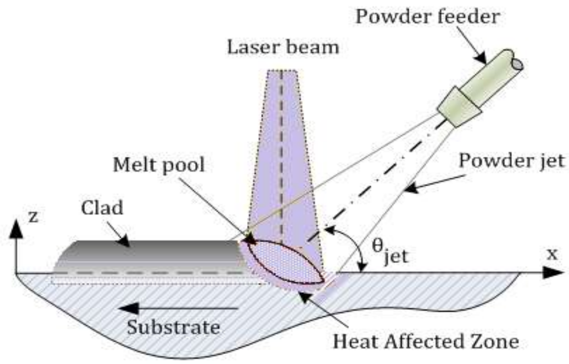

Fig. 1: Laser cladding process

Wang et al. (2001) investigated YAG laser cladding of an Al-Si alloy onto an Mg/SiC composite for the improvement of corrosion resistance. Results indicated that a new layer, the diffusive layer, was found in the laser-clad Al–Si alloy coating on an Mg/SiC composite substrate, which was different from the laser-clad coatings on other substrates such as steels, cast irons and aluminium alloys. The laser-clad coating has a structure of Al–Si eutectic and exhibited the best corrosion resistance due to the absence of Mg_2Si. Riveiro at al. (2013) studied about the optimization of laser cladding for Al coating production. The results showed the feasibility of diode laser cladding for the production of aluminum coatings was demonstrated. Clad tracks, approximately, 4.5 mm in width, 0.66 mm in depth, and 1.25 mm in height were produced. Behaviour of geometric characteristics of the clad tracks as a function of the processing parameters has also been determined. Total costs of the process have been studied and the contribution of each part of the process determined. Influence of each parameter on the total cost of the process reveals the filler material as the most influential parameter. This parameter is more decisive on the total cost than the laser unit and cooling system. This rejects the conventional idea of the high capital cost related to the laser source, because its influence in the total cost of the process is limited compared to the contribution of filler material to the total cost of the process or the gas consumption.

Ming Qian et al. (2008) investigated the microstructure and corrosion characteristics of laser-alloyed magnesium alloy AZ91D with Al–Si powder. The results have shown that excellent alloyed layers of metallurgical bonding were achieved in the laser alloying of AZ91D with Al–Si powder. For the alloy AZ91D base metal, corrosion preferentially occurred at the Mg matrix. AZ91D laser-alloyed Al–Si layers exhibited improved corrosion resistance. Tobar at al. (2014) investigated the Laser Cladding of MCrAlY coatings on stainless steel. The results indicated that three types of commercially available MCrAlY alloys mainly differing in NiCo matrix composition and Al content were deposited by laser cladding on austenitic substrates. Dense layers with metallurgical bonding were obtained in all cases. The use of laser cladding technique as an alternative to plasma spray or HVOF methods, yielding fully dense coatings with metallurgical bonds to substrate. Other characteristics of the coatings as corrosion and mechanical resistance are currently under study. Zheng et al. (2010) investigated the microstructure and wear property of laser cladding Al+SiC powders on AZ91D magnesium alloy. The results showed that the laser cladding treatment on AZ91D magnesium alloy produced a fine dendritic and cellular structure. XRD analyses showed that the laser cladding layer was consisted of $Mg_{17}Al_{12}$, SiC, Al and Mg. 30 wt% SiC showed the minimum wear volume loss and an obvious increased microhardness.

Investigation of mechanical properties and microstructures of AZ91D magnesium alloy processed by selective laser cladding with Al powder was carried out by Bernabe Pengyu Lin et al. (2014). This process generated a hardened layer which showed good metallurgical bonding with the matrix, and moreover the microstructure was greatly refined. Wear resistance was improved with increasing microhardness. Murzakov et al. (2015) investigated the structure formation and properties of weld overlay produced by laser cladding under the influence of nanoparticles of high-melting compounds. The results shows that weld deposit overlay with additives of TaC nanoparticles at various weight concentrations (5, 10, 15, 20%) were obtained. Mechanical tests on overlay abrasive resistance were made and showed 4-6 times decrease in the weight loss along with the increase of concentration of nano-additives of tantalum carbide. Metallographic studies of weld deposits obtained with nano-WC additives of various concentrations were conducted. A study of reflection spectrum of backscattered electrons along the transverse cross-section of welding deposition at five points was carried out. Comparative analysis of overlay microhardness without WC nanoparticles and with the addition of nanopowder showed that there has been an increase in microhardness from 6000 MPa to 9000 MPa. Yue et al. (2014) studied about solidification behaviour in laser cladding of AlCoCrCuFeNi high-entropy alloy on magnesium substrates. Result showed that the AlCoCrCuFeNi multi-component alloy could be fabricated on magnesium substrates using laser cladding. The top layer of the coating was a dense AlCoCrCuFeNi HEA layer, below which there was a composite layer containing partially melted HEA powders in an Mg rich matrix. This was considered to be important because any dilution of the HEA composition with Mg would likely lower the corrosion resistance of the HEA.

C. *Plasma Cladding*

Plasma cladding machine built according to customer's demand, built for the repair of ones. This machine does not only include cladding; it is also designed to be closely linked three dimensional CAD software allows to tailor the best pattern before any production. The fully automated 6 axes CNC machine will then guarantee that parts up to 15 m can be cladded with the highest quality standard. In many types of industrial machinery, surface damage generated by sliding or abrasive wear limits the life of the components and therefore reduces their durability and reliability. This drives the development of wear-resistant coatings and films that enable to improve the performance of engineering components under different conditions. Low heat input keeps dilution to a minimum and the alloy maintains optimum wear-resistant properties. The heat affected zone is very thin under the surface and part distortion is avoided. Thin walled components are not damaged and mechanical properties are not significantly modified, Reproducible process. Homogeneous coating deposition occurred with a constant and controlled quality.

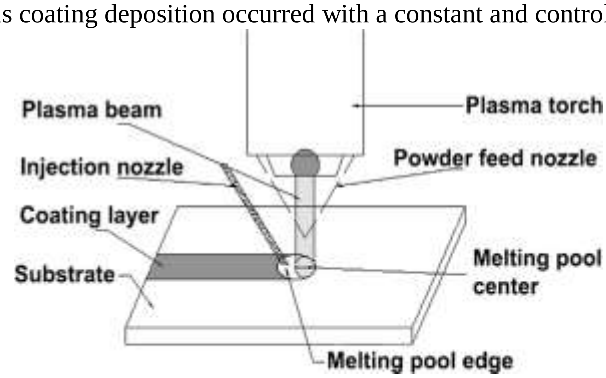

Fig. 2: Plasma cladding process

Chucheng Lin et al. (2013) investigated the microstructures and tribological properties of vacuum plasma sprayed B_4C–Ni composite coatings. The results obtained showed that nickel borides were produced during spraying in the composite coating, which improved the wettability of the carbide phase by the matrix and led to an enhancement of the carbide–matrix interface strength. Due to the more homogenous microstructure and effective protection from the compact transfer layer on the worn surface, the B_4C–Ni composite coating exhibited both lower friction coefficient and volume wear rate than those of the pure B_4C coating while matching with WC–Co alloy under the conditions used in the present study. The improvement in wear resistance of the B_4C/Ni composite coating was also attributed to its higher thermal conductivity, since the concentration of frictional heat was alleviated in the real contact areas. For the coatings investigated, the dominant wear mechanisms were a mixture of oxidation and tribofilm wear. Yezhe Lyu et al. (2015) investigated on the microstructure and wear resistance of Fe-based composite coatings processed by plasma cladding with B_4C injection. The results showed that injection of B_4C at the center of the melting pool resulted in the dissolution of B_4C particles and generation of cementite in the microstructure. Injection of B_4C at the edge of the melting pool (2–4 mm from the center of melting pool) remained the B_4C particles in the final Fe-based coatings. B_4C particles distributed dispersedly and performed strong metallurgical bonding with the Fe-based matrix. Wear resistance was largely increased with the deposition of Fe-based coatings. Mohammed Jasim et al. (2013) investigated the laser sealing of zirconia–yttria–alumina plasma sprayed coating. The results indicated that the relationship between the features of the sealed coatings, such as sealed width, depth of sealing, depth of concavity, cell size and crack width with processing conditions such as traverse speed and specific energy showed that the optimized sealing is obtained at power surface densities less than 61 W/mm^2. The sealed coatings have been characterized with crack network and depressions; their width and depth, respectively, are shallow under an optimum laser flounce of less than 2.5 J/mm^2. Sealing coatings up to 100 µm were successfully obtained with a small volume fraction of depressions characterized with high hardness and fracture toughness.

Thirumalaikumarasamy et al. (2014) investigated the influence of chloride ion concentration on immersion corrosion behaviour of plasma sprayed alumina coatings on AZ31B magnesium alloy. The results indicated that the uncoated and alumina coated samples were found to offer a superior corrosion resistance in lower chloride ion concentration NaCl solution. The corrosion rates of the uncoated magnesium and alumina coatings were increased with increasing chloride ion concentration, suggesting the uncoated and alumina coated AZ31 alloys are more reactive in higher chloride ion concentrated solutions. The level of the corrosion attack is much higher when chloride ion concentration is greater than 0.6 M, which was validated by the surface micrographs and macrographs. The uncoated and plasma sprayed alumina coatings on AZ31B magnesium alloy were found to be highly susceptible to localized damage, and could not provide an effective corrosion protection in solutions containing higher chloride concentrations. It means that the both the coatings and substrate had a better corrosion protection in NaCl solution than in higher concentration NaCl solution.

D. Roll Bonding
Roll bonding is a solid state, cold welding process, obtained through flat rolling of sheet metals. In roll bonding, two or more layers of different metals are passed through a pair of flat rollers under sufficient pressure to bond the layers. The pressure is high enough to deform the metals and reduce the combined thickness of the clad material. The mating surfaces must be previously prepared (scratched, cleaned, degreased) in order to increase their friction coefficient and remove any oxide layers. The process can be performed at room temperature or at warm conditions. Heat may be applied in order to improve the ductility of metals and improve the strength of the weld. The applications of roll bonding can be used for cladding of metal sheets, or as a sub-step of the accumulative roll bonding. Bonding of the sheets can be controlled by painting a pattern on one sheet; only the bare metal surfaces bond and un-bonded portion can be inflated if the sheet is heated and the coating vaporizes. This concept is used to make heat exchangers for refrigeration equipment.

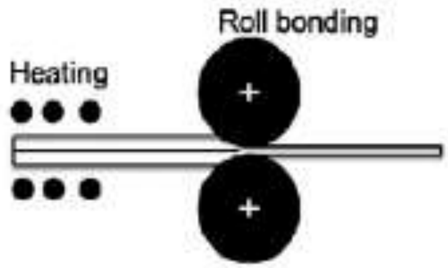

Fig. 3: Roll bonding process

Farmanesh et al. (2015) investigated the microstructural and mechanical properties of nano/ultra-fine structured 7075 aluminum alloy by accumulative roll-bonding Process. The results showed that UFG microstructures were formed in the 7075 aluminum alloy highly deformed by the ARB process. The tensile strength of the ARB processed 7075 Al alloy increases with the number of ARB cycles so that the specimen after five cycles shows UTS of 470 MPa, which is about three times as much as that in the annealed state. The hardness of the ARB processed 7075 Al increased with the number of ARB cycles so that the specimen after eight cycles achieved the highest hardness of about 112% higher than the initial value. Fracture morphology shows a ductile fracture even after ARB.

However, the amounts of micro voids are less. In addition, due to fine grains, fine shear lips are observed. Therefore, at higher strains of 2.4 and 4.8, the macrographs clearly indicate the absence of necking and the presence of shear feature. Akira Yanagida et al. (2013) studied the finite element simulation of accumulative roll-bonding process. The exact magnitude and distribution of the equivalent strain in the Al sheet processed during three ARB cycles using FEA were shown in their study. These quantitative strain analyses would provide useful guidelines for understanding the quantitative correlation between the microstructures and strain in the ARB process.

Evaluation of mechanical properties and structure of 1100-Al reinforced with ZrO_2 nano-particles via accumulatively roll-bonding process was carried out by Salimi et al. (2015). Al/Nano-ZrO_2 composites were manufactured through 10 cycles of cold roll-bonding process; which is an attempt to use pure metal particle-reinforced AMMCs. The microstructure and mechanical properties of the composites were investigated. Proper distribution of reinforcing particles ZrO_2 in aluminum is obtained during ARB process. Composite produced the strength increased; the elongation was decreased in the first few cycles and then increased as ARB process cycles continued. Lee et al. (2011) investigated the effect of thermomechanical treatment on the interface microstructure and local mechanical properties of roll bonded pure Ti/439 stainless steel multilayered materials. Although additional generation of diffusion layer together with increase in the thickness of initially-formed diffusion layer takes place with progressing hot roll cladding processes followed by proper annealing, there is no sign of detrimental reaction products like intermetallic compounds within interdiffusion layer except solid-solution reaction resulting in considerable increase of hardness from 6.87 GPA to 8.09 GPa. Hasannia et al. (2013) investigated the nanograined Ti–Nb microalloy steel achieved by ARB process and an ultra-fine structure was obtained in accumulative roll bonding. The UFG material showed higher hardness, yield and tensile strength compared to its conventionally grained counterpart, but unfortunately showed only limited ductility. Hardness and yield strength of UFG material are typically 2.35 and 3.34 times respectively higher than that of the conventionally grained counterpart. The elongation to failure decreased after the first few ARB cycles and was significantly lower in comparison to the as-received materials. In the UFG Ti–Nb microalloy steel the maximum elongation to failure in the rolling direction reached upto2.9%. Charles et al. (2010) investigated the cyclic deformation behavior of ultra-fine grained copper processed by accumulative roll-bonding. The results showed that due to the composite nature of the microstructure in the as received ARB copper, the conventional equiaxial grains, i.e. the large grains, were able to accommodate a fraction of the applied cyclic plastic strain through the development of slip bands within them. Grain coarsening was observed when the samples were subjected to cyclic loading both in load controlled tests and in strain controlled test. Grain coarsening might be indirectly leads to cyclic creep behavior and the cyclic softening behavior observed via the increase in volume fraction of large-sized grains capable of developing slip bands within them.

E. Explosive Cladding
Explosive cladding is also known as explosion welding. It is the bonding of two or more dissimilar of explosives. It is accomplished by a high-velocity oblique impact between two metals. The impact produces sufficient energy to cause the colliding metal surfaces

to flow hydro intimately contact one another in order to promote solid-state bonding. The metal surfaces under high pressure from the explosion, and an atomistic bonding occurred between the dissimilar metals. Explosive cladding is a 'pressure weld process at room temperature'.

It is a method is welded by conventional processes, such as titanium-steel, aluminium-steel and aluminium-used to weld compatible metals, such as stainless steels and nickel alloys to steel. The cladding stainless steel, duplex steel, titanium, aluminium, copper, copper alloys, nickel, nickel alloys. Explosion-welded clad metals are used in a wide range of industries like oil and gas, chemical desalination plants, steel mills & hydrometallurgy, aluminium smelters, shipbuilding, power industries where corrosion, temperature and pressure are important parameters.

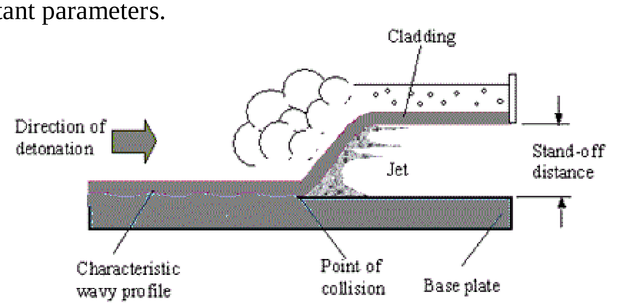

Fig. 4: Explosive cladding process

Sudha et al. (2014) investigated the assessment of mechanical property of Ti-5Ta-2Nb and 304L SS explosive clad and correlation with microstructure. The results showed that explosive cladding of Ti-5Ta-2Nb on 304L SS resulted in deformation induced phase transformation in stainless steel. Formation of deformation induced martensite in 304L SS lead to increase in UTS and YS and decrease in ductility. Bond strength in the longitudinal direction was satisfactory whereas in the transverse direction the clad did not meet the specifications. Intermetallic phases were not detected in 'as received' explosive clads within the resolution limit of an electron microprobe. However, electron microscopy investigations suggested their presence at isolated pockets at the clad interface. Heat treatment of the explosive clads have to be restricted to temperatures less than 873K and durations below 10 hours to avoid the formation of a continuous network of intermetallic phases parallel to the clad interface.

Extensive characterisation of copper-clad plates, bonded by the explosive technique, for ITER electrical joints was done by Langeslag et al. (2015). Mechanical measurements in terms of tensile and shear tests have demonstrated that the properties of the examined clad plates were dominated by the individual materials. Independent of potential imperfections observed at the bonded interface, the bimetal failed consistently in the weaker copper cladding. It implicates that for an electrical joint, connecting unit lengths of coils working in a pulsed regime, the use of a lower purity copper cladding could be a compromise. A low RRR copper cladding will reduce loop currents, hence temperature rise, and increase the superconductor stability margin.

III. CONCLUSION

Various researchers has been used different cladding processes for bonding of dissimilar metals; however laser cladding is found to be one of the effective method and suitable for almost all materials. It provides perfect metallurgically bonded and fully dense coatings. Minimal heat affected zone and low dilution between the substrate and filler material result in functional coatings that perform at reduced thickness, so fewer layers are applied. Extended weldability of sensitive materials like carbon-rich steels or nickel-based super alloys that are difficult or even impossible to weld using conventional welding processes can be done using laser cladding. It is often used to improve mechanical properties, corrosion resistance, wear resistance, repair worn out parts.

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