Laser Cladding Coatings on Magnesium Alloys

Subjects: Materials Science, Coatings & Films

Contributor: Ainhoa Riquelme

The surface properties of magnesium alloys can be improved by Laser Cladding in order to increase wear and corrosion resistance manteining the lower density of these alloys. This can make magnesium alloys a promising structural material to be used as a substitute for metals traditionally used in the automotive and aircraft sector.

laser cladding magnesium coatings

1. Introduction

Magnesium alloys have a great potential to be used as a structural material due to their low density, which leads to very high specific mechanical properties, comparable to those of some steels. In addition, their ease of machining and low cost make them suitable alloys for use in the transportation industry. The main limitations of these alloys are the low surface properties, since they have low wear and corrosion resistance, reducing their field of application [1][2][3].

One of the strategies that can be followed to improve this limitation is to make protective surface coatings by laser cladding techniques. The main advantages that laser cladding offers compared to other more traditional techniques are better surface properties with minimal dilution, minimal substrate thermal distortion and better surface quality. To obtain coatings with good mechanical characteristics, it is necessary to select the appropriate process parameters for which it is necessary to know the effect that these have on the resulting coating. The effect of parameters such as laser power, scanning speed, powder feed, as well as the properties of both the substrate and the powder on the obtained coatings has led to several studies. The variation of any of these parameters turns into changes in the morphology, width or height, as well as in the metallurgical characteristics of the coating, microstructure, degree of dilution, porosity, etc. [4][5].

2. Laser Alloying, Glazing, and Cladding

Laser cladding is a coating manufacture method with which it is possible to obtain low porous and improved properties coatings on different materials (mainly metals) using a laser as energy source. Based on the feed material, the amount of molten substrate and the laser parameters, three varieties of this process can be established: laser alloying, laser glazing and laser cladding. In the three cases, the high cooling rate and, consequently the quick solidification during the fabrication process is the main advantage of these methods, because it results in a fine microstructure and improved mechanical properties. During the solidification process, the melted metal liquid atoms are joined together at the nucleation points and start to form crystals. These crystals grow and form grains in the direction of the solidification, however, due to the high cooling rates, these grains have no time to become bigger, and their size ends up being very small in this kind of process. Small grain sizes result in high number of grain limits and, consequently, in high hardness and mechanical properties [6].

Laser alloying technique allows to melt simultaneously the feeding material and the substrate obtaining a homogeneous alloyed metal. In general, the coating is not very thick because the amount of spraying material is low [7].

Laser glazing allows to melt only a small part of the substrate and cool it very quickly (10^{10}–10^{12} K/s), which forms amorphous crystal [8][9][10][11].

Coatings with different composition to the substrate have been successfully fabricated by Laser cladding technique since this method produces a minimum dilution of the substrate allowing the coating to maintain the feed material properties. Moreover, a fine coating microstructure is obtained due to the quick cool rate. To achieve this, the control of the laser parameters is very important.

The main problem of lasers techniques on magnesium alloys is that the use of magnesium as a substrate, together with high values of laser power, can produce a dilution of the magnesium from the substrate to within the coating matrix due to the low melting points of magnesium alloys (~560 °C) that makes them liable to be melted during the laser cladding process. Nevertheless, this dilution changes with the processing parameters, therefore, obtaining a minimal dilution rate is possible. Indeed, the three methods of coatings fabrication (laser alloying, laser glazing and laser cladding) are feasible on magnesium alloys.

For instance, Ignat et al. [12] obtained hardened high corrosion resistance Al/Mg coatings on WE43 and ZE41 magnesium alloys by laser alloying. Other authors such as Yue, Su, and Yang [8] and Huang et al. [9] developed amorphous coatings by laser glazing. However, avoiding dilution is possible by using low laser power. Yang et al. [13] used laser cladding to coat ZE91D magnesium alloys with Al + (Ti + B_4C) composite coatings and A. H. Wang et al. [14] utilized laser cladding to repair surface areas of magnesium components.

Obtaining improved coatings with homogeneous compositions, low porosity, minimal interactions between the molten pool and the sprayed material, and greater properties depends on the laser parameters and on the amount of the feed material used. Indeed, most laser cladding coatings are actually laser alloying coatings.

Figure 1 shows a scheme of laser alloying, glazing and cladding. The classification is based on the mixed composition between the magnesium of the substrate and the elements of the coatings [6]. In addition, **Figure 1** shows an example of the resulting microstructure. The main differences between the microstructure showed in **Figure 1**a,c is that in the case of laser alloying, there is a higher dilution between the coating and the substrate, and the resultant material is embedded in the substrate surface. In the case of the laser cladding microstructure, the coating is on the substrate surface, not embedded in the substrate. In the case of the laser glazing microstructure shown in **Figure 1**b, the morphology/shape of the coating is similar to laser cladding, however, the coating is an amorphous crystal.

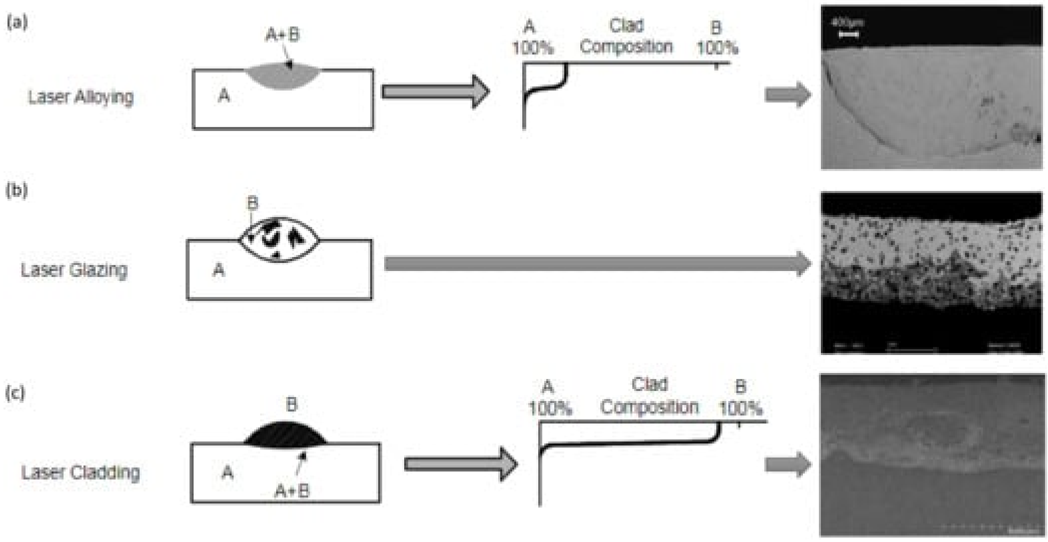

Figure 1. Scheme of laser alloying, glazing and cladding [6]; (**a**) Al laser alloying coating on ZE41. Reprinted with permission from ref. [7]. Copyright 2021 Elsevier; (**b**) 65Al7.5Ni10Cu17.5 reinforced with SiC particles amorphous coating on Mg substrate. Reprinted with permission from ref. [10]. Copyright 2021 Elsevier; (**c**) A12Si/SiC laser cladding coating on ZE41 alloy. Reprinted with permission from ref. [15]. Copyright 2021 Elsevier.

3. Laser Cladding on Magnesium Alloys

Laser cladding is an effective fabrication process to obtain surface layers with improved properties, good metallurgic bonding with lack of defects, and low dilution that can be achieved in comparison with conventional methods like thermal spraying or arc welding. The use of a laser as an energy source is key to these advantages.

Furthermore, from a manufacturing point of view, laser cladding has other benefits: decreasing manufacturing times; increasing cooling and solidification rates; no restrictions on the fabrication of complicated geometries and repair of components.

The coating process was carried out with a laser cladding system consisting of a laser (different kind of lasers are possible, for instance: diode laser (848 nm), Nd:Yag laser (1064 nm), CO_2 laser (10.64 µm), and excimer laser (248 nm)). In most cases, the feeding material is in the form of spherical powder which is generally sprayed with a carrier gas (generally Argon) and coaxially with the laser beam trough a cladding nozzle (normally a coaxial nozzle). Moreover, other forms of feeding material are possible as is shown in **Figure 2**. For example, paste feeding (**Figure 2**a) when the raw material is in a paste shape, wire feeding (**Figure 2**c) when it is in a wire shape or preplaced powder, where the raw powder is previously deposited on the substrate surface, and then the laser passes over this powder and melts it, and a minimal part of the substrate surface forms the coating [6]. The laser with the cladding nozzle is connected to a motor control system, it generally consists of a CAD (computer-assisted draughting) system and a motion robot or a x-y motion table. **Figure 3** shows the scheme of an equipment of laser cladding [16].

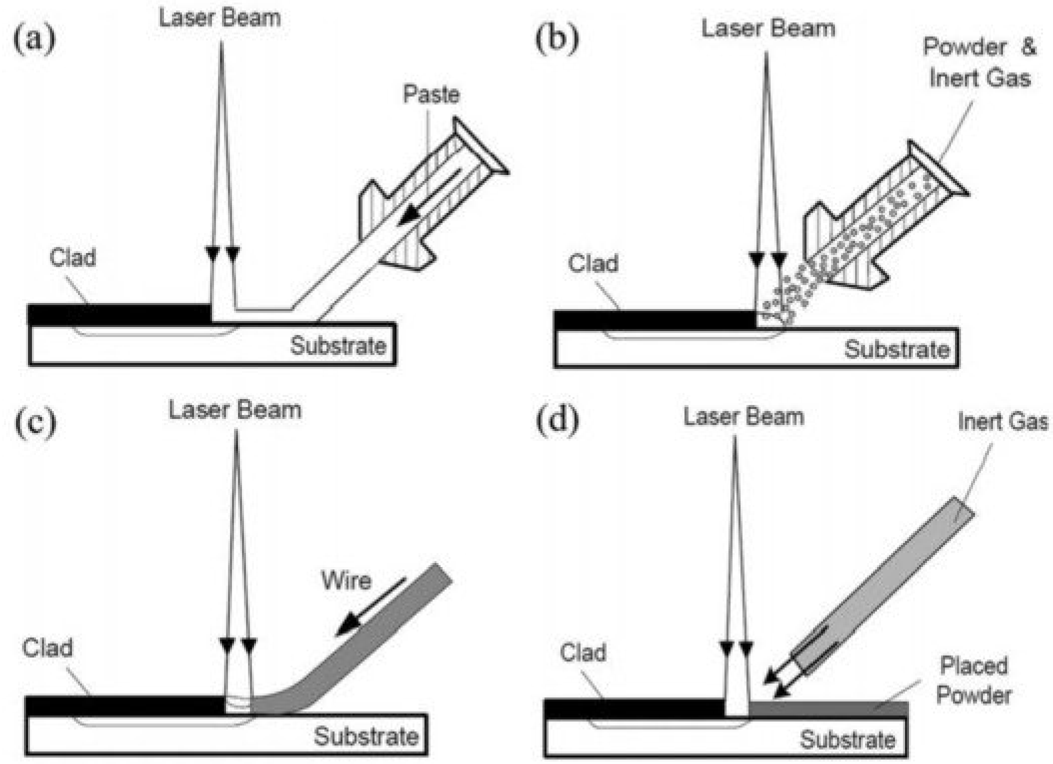

Figure 2. Different methods of laser cladding feeder: (**a**) paste feeding; (**b**) powder injection; (**c**) wire feeding; (**d**) preplaced powder [6].

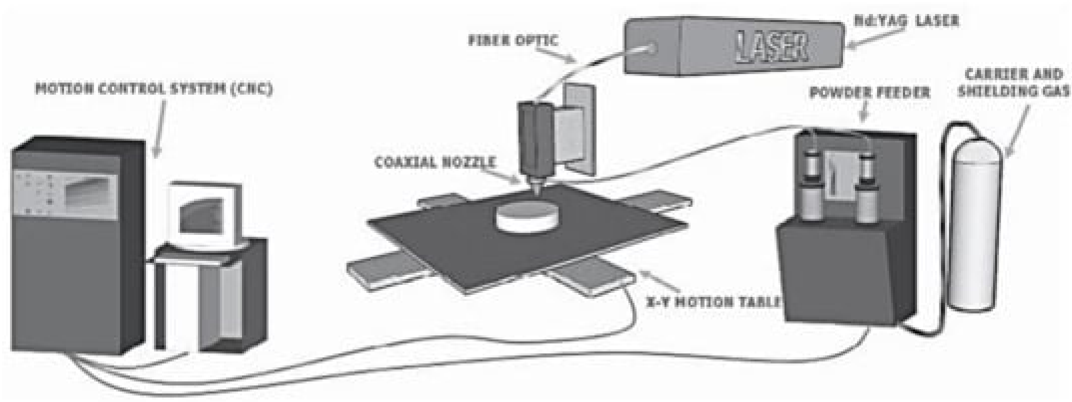

Figure 3. Scheme of laser cladding equipment. Reprinted with permission from ref. [16]. Copyright 2021 Elsevier.

References

1. Cole, G.; Sherman, A. Light weight materials for automotive applications. Mater. Charact. 1995, 35, 3–9.

2. Ostrovsky, L.; Henn, Y. Present state and future of magnesium application in aerospace industry. In Proceedings of the International Conference “New Challenges in Aeronautics” ASTEC 07, Moscow, Russia, 19–22 August 2007; pp. 19–22.
3. Kulekci, M.K. Magnesium and its alloys applications in automotive industry. Int. J. Adv. Manuf. Technol. 2008, 39, 851–865.
4. Zhong, M.; Liu, W. Laser surface cladding: The state of the art and challenges. Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci. 2010, 224, 1041–1060.
5. Das, A.K. Recent trends in laser cladding and alloying on magnesium alloys: A review. Mater. Today Proc. 2021, in press.
6. Toyserkani, E.; Khajepour, A.; Corbin, S. Laser Cladding; CRC Press: Boca Raton, FL, USA, 2004.
7. Ignat, S.; Sallamand, P.; Grevey, D.; Lambertin, M. Magnesium alloys laser (Nd:YAG) cladding and alloying with side injection of aluminium powder. Appl. Surf. Sci. 2004, 225, 124–134.
8. Yue, T.; Su, Y.; Yang, H. Laser cladding of Zr65Al7.5Ni10Cu17.5 amorphous alloy on magnesium. Mater. Lett. 2007, 61, 209–212.
9. Huang, K.; Xie, C.; Yue, T.M. Microstructure of cu-based amorphous composite coatings on AZ91D magnesium alloy by laser cladding. J. Mater. Sci. Technol. 2009, 25, 492–498.
10. Yue, T.M.; Su, Y. Laser cladding of SiC reinforced Zr65Al7.5Ni10Cu17.5 amorphous coating on magnesium substrate. Appl. Surf. Sci. 2008, 255, 1692–1698.
11. Su, Y.; Yue, T. Microstructures of the bonding area in laser cladded Zr-based amorphous alloy coating on magnesium. Mater. Today Commun. 2020, 25, 101715.
12. Ignat, S.; Sallamand, P.; Grevey, D.; Lambertin, M. Magnesium alloys (WE43 and ZE41) characterisation for laser applications. Appl. Surf. Sci. 2004, 233, 382–391.
13. Yang, L.; Li, Z.; Zhang, Y.; Wei, S.; Liu, F. Al-TiC in situ composite coating fabricated by low power pulsed laser cladding on AZ91D magnesium alloy. Appl. Surf. Sci. 2018, 435, 1187–1198.
14. Wang, A.; Xia, H.; Wang, W.; Bai, Z.; Zhu, X.; Xie, C. YAG laser cladding of homogenous coating onto magnesium alloy. Mater. Lett. 2006, 60, 850–853.
15. Riquelme, A.; Rodrigo, P.; Escalera-Rodríguez, M.D.; Rams, J. Analysis and optimization of process parameters in Al–SiCp laser cladding. Opt. Lasers Eng. 2016, 78, 165–173.
16. Carcel, B.; Sampedro, J.; Ruescas, A.; Toneu, X. Corrosion and wear resistance improvement of magnesium alloys by laser cladding with Al-Si. Phys. Procedia 2011, 12, 353–363.