Laser treatment of alloys

de Oliveira, Uazir Orion Bezerra

Publication date:
2007

Summary

The surface condition of a component is usually the most important engineering factor. Almost inevitably the outer surface of a work-piece is subjected to wear and corrosion while it is in use. To an increasing degree, therefore, the search is for surface modification techniques, which can increase the wear resistance of materials. It is worth noting here that wear resistance is a property, not of materials but of systems, since the material of the work-piece always wears against some other medium. It is its relation to its environment – e.g. lubrication, speed of sliding/rotation - that determines the wear resistance of the material in a given construction. As a general rule, wear is determined by the interplay of two opposing properties: ductility and hardness.

In this thesis two high-power laser techniques are used for the surface engineering of metallic alloys:

Laser cladding, which allows the deposition of thick resistant metallic by a melting process fusing a special alloy onto a weaker substrate.

Laser hardening, which produces wear resistant tracks by microstructural transformations, i.e. a laser beam scans across a component without melting. For instance, in steels or ferrous alloys a temperature above 1200 ^{o}C should be avoided.

In this work application of the laser hardening process on gray cast iron, a material that is widely used in engineering components, is investigated based on the observations of microstructure transformations. An important conclusion is that the surface quality of gray cast iron can be improved by temperature controlled laser surface hardening. The microhardness of GG-25 cast iron laser treated tracks increased from 250 to 500-1000 H_V in the transformed zone that consisted mainly of martensite, retained austenite and remaining cementite lamellae and undissolved graphite flakes.

Next, the influence of the process parameters and alloys on the microstructure of laser deposited clad layers is thoroughly investigated by means of EBSD microscopy techniques. It is shown that a graded method experiment can be applied to determine the optimal operation window of the laser cladding technique with different set-ups. The experiment in which the Nd:YAG laser power is gradually increased during laser cladding of a single laser track while other two main process parameters (scanning speed and powder feeding rate) are fixed, reduces substantial the cladding experiments that are required for a proper study of the processing window. In general, it can be concluded that the main advantage of the coaxial laser deposition set-up lies in its directional independence while the side cladding set up is directional dependent. On the other hand, the side cladding set-up provides higher powder efficiency and a larger processing window can be defined. A theoretical model of the coaxial laser cladding is presented revealing the influence of the powder fly velocity on the quality of the deposited clad.

Four kinds of Co-based alloys were used to build clad layers on the surface of C45 or gray cast iron substrates. The microstructure of the clad tracks characterized by optical and electron microscopy techniques (SEM, TEM and OIM) revealed coarse grains

composed of fine dendrites. The phases analysis performed by lab and synchrotron x-rays reveals a γ-Co based matrix and carbide precipitates (M_7C_3, $M_{23}C_6$, and Co6WC) in the eutectic area located in the interdendritic spaces.

The morphology of the clad layers, investigated by EBSD patterning microscopy depends greatly on the speed of the laser cladding process. It was observed that the microstructure morphology of a single clad track becomes more homogeneous with the increase of process speed. Slowly deposited tracks presented grains 10 times bigger when observed at the longitudinal cross section plane than in the transverse cross section. In contrast, under high speed the grain sizes were comparable in the longitudinal and the transverse directions. Overall, refinement of the microstructure takes place from the top towards the interface with the substrate. Grain coarsening takes place in the overlap area of neighboring tracks caused by the remelting provoked when a clad layer is deposited.

Crystallographic texture dependence with the velocity is also observed. Low speed deposited samples showed a multiple fiber texture when observed in the transverse cross section. In the case of fast deposition the samples show preferential fiber textures along the axis of the processing direction. A strong fiber texture is found in the longitudinal direction. The texture is normal to the surface in the slower case and tilted 45^o in relation to the substrate in the faster deposition case.

The microstructure of a laser deposited tool steel clad layer investigated by EBSD patterning microscopy is fine grained and dendritic, with the presence of subdendritic martensite grains and retained austenite on the rate of 60 to 40%, respectively. The application of this powder for the construction of clad layers is very promising due to its crack resistance observed during the deposition experiments.

A drawback of the laser cladding is the high tensile residual stresses that may be created in the coatings due to the melting followed by resolidification of the layer and provoke degradation of the coating mechanical properties, or even may provoke cracking of the layer during deposition. Macro and micro residual stresses were investigated in Co-based clad layers by lab and synchrotron x-rays diffraction techniques.

Macrostresses in Co-based clad layers:

The stress state the Stellite 20 clad layer, investigated by lab x-rays, is biaxial. The major stress component is much larger than the minor one and it is tilted about 40º from the cladding direction. This behavior is connected with the change of the cooling front propagation during the overlapping of laser tracks when the clad layer is built. When synchrotron x-rays are applied in reflection mode the coarse and textured microstructure of the intact Co-based laser track does not contribute for performing the macrostress analysis through the whole coating depth.

Tensile residual macrostresses are found in Co-based clad layers investigated by synchrotron x-rays. The value of the stresses usually increases with depth and may reach maximum values at half of the thickness of the coating. Near the coating/substrate interface the nature of the internal stresses is changed to compressive.

The variation of the stress as a function of depth is not smooth and also its behavior varies from track to track. The residual macrostresses of Co-based clad layers increase with scanning speed, track overlapping and change from flat to round shape of the substrate.

Microstresses in Co-based clad layers:

A laser deposited Eutrolloy16012 Co-based coating was investigated by 3DXRD microscopy in order to determine individual grain microstresses. The residual microstrains were accessed under high spatial resolution defined by the size of the synchrotron microbeam. γ-Co grains were successfully identified and localized in the microstructure by 3DXRD microscopy in agreement to the microstructural observations.

Residual microstrains and stresses were analyzed in terms of tensor invariants, hydrostatic and von Mises stress, along the depth of a slightly diluted clad track. The upper part of the coating shows a constant spread of hydrostatic stresses between –500 and 500 MPa; towards the bottom of the track the spread of these stresses increases almost linearly with depth. The behavior of overall macrostress determined as an average of the microstresses shows a previously observed trend in macrostresses when tensile stresses at the top of the coating are gradually changed to the compressive stresses near the coating/substrate interface.

Macrostresses in Fe-based clad layers:

Residual macrostresses of an Fe-based clad layer was investigated by lab x-ray diffraction and correlated with its microstructure. The macrostress state near the surface of the clad is compressive and the larger principal stress lies along the cladding direction. A large amount of martensite formed is responsible for the compressive state due to the expansion of the crystal lattice. The fine and randomly oriented grains contribute for breaking the stress orientation relation with the solidification front so that the larger principal stress lies along the cladding direction instead of tilted as it is the case of the Stellite 20.

Finally, the wear behavior of Co-based alloy claddings is tested by dry sliding in a range of temperatures that span from the room to typical automotive engine application temperatures. The oxidative wear mechanisms active in different regimes is also discussed. Clad layer samples meant for dry sliding tests were deposited according the processing map presented in this thesis. The Eutrolloy 16006 alloy was successfully deposited on a gray cast iron substrate and its characterization showed no signs of macro defects.

The dry sliding behavior of the Eutrolloy 16006 alloy was tested in the temperature range of automotive engine applications. The wear rate and the friction coefficient behave in two different regimes depending on the temperature of the test. From room temperature to 275 ^{o}C the coefficient decreases and the wear rate increases. Above this temperature until 525 ^{o}C the opposite behavior has been observed, i.e. the friction coefficient starts to increase, whereas the wear rate decreases with temperature. The creation of a compact oxide layer formed between the metal-metal contact above the 275 ^{o}C is the responsible for the decrease of the friction coefficient.

In summary; this work contributes to a deeper understanding of laser processing technology and its potential applications. Laser processing can provide unique challenges and opportunities based on high spatial precision, reproducibility and automatic control.