Microstructure and Mechanical Properties of Laser Cladded Steel Plates

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Abstract

A low alloyed hypo-eutectoid steel plate was cladded with a cobalt-chrome alloy by means of a laser. Subsequently, the layered structure was examined by metallographic inspection, by hardness measurement, and mecanically. The latter consisted of tensile tests and low-cycle-fatigue. The cladding resulted in a structure with high interfacial strength and good ductility.

Key words: Laser cladding, Co-Cr, carbon steel, microstructure, deformation behaviour, fatigue properties.

1 Introduction

The process of laser cladding consists of the injection of powder into the meltpool created by a laser beam on the surface of a substrate material. The laser beam and, thus, the meltpool are scanned over the surface, resulting in a single track of a surface layer on the substrate. By applying the process in several passes (or multipass), one beside the other, the whole surface can be coated. The clad is metallurgically bonded to the substrate with a very small intermixing zone between the clad and the substrate. During cladding the substrate is heated and subsequently cooled with high rates, as it acts as heat sink. This leads to the so-called heat affected zone (HAZ) under the clad. The HAZ can change its microstructure owing to e.g. a phase transformation within the temperature range that is encountered. In addition, during multipass cladding several thermal cycles can change the newly created phases further.

Clads produced by means of laser possess unique properties compared to other techniques. First, they are very compact without noticeable porosity. Second, the bonding between the clad and the substrate is very strong owing to the metallurgical bonding. Third, the high heating and cooling rates often results

Table 1
Composition of the clad powder and the substrate in [wt.%]

Element	Fe	C	Co	Cr	Mo	Ni	Si	S & P	Mn	V
Clad	0.35	0.125	bal	25.5	5.6	2.15	1.01			
Sub	bal	0.51		0.13	0.029	0.11	0.32	<0.03	0.72	0.051

in non equilibrium phases. In addition, the process is fast and can easily be automated. In recent years laser cladding has attracted more and more attention. Microstructure, phase identification, and hardness measurement were the fundamental interests of such studies [1,2]. This paper additionally deals with mecanical behaviour.

2 Experiments

First, a test plate of plain carbon steel (commercial name SURA B82) was cut and ground to the dimension of 200 mm x 10 mm x 20 mm. The clad was applied on the top surface by moving the laser beam in the longitudinal direction. Successive passes were introduced by parallel runs in the same direction with 2 mm displacements (transversal). After cladding of the whole surface a second layer was put on top of the first one, resulting in about a 2 mm thick clad on top of the substrate. Underlying the clad a 1 mm thick HAZ has developed. From this test plate all the samples and specimens were taken. Table 1 shows the chemical composition of the two materials. The fatigue properties of this material and variants of it was recently studied by Ahlström [3].

Next, metallographic examination and hardness measurements of the test plate were done perpendicular to the direction of the passes. Samples from the plate were ground, polished, and finally etched, using a 2 % Nital solution in order to show the microstructure in the HAZ and the substrate. Vickers hardness was measured at two positions using a load of 10 kg. One position was in the middle of a cladding pass, the other between two subsequent passes.

Then, tensile testing was performed on specimens both in the longitudinal and transversal directions. The specimen had a nearly squared cross section of about 4 mm side, with a clad thickness of about 1.6 mm. Before conducting the tests, the specimen were ground in the tensile direction down to paper 1200 in order to minimize surface effects. The test itself was conducted using a strain rate of 10^{-4} s^{-1}.

For fatigue testing total strain control was employed with a triangular wave shape and symmetric loading ($R_\epsilon = -1$) at $\dot{\epsilon} = 10^{-2}$ s^{-1}. The test specimens had a thickness of around 7.5 mm, whereof the clad is about 1.8 mm, and

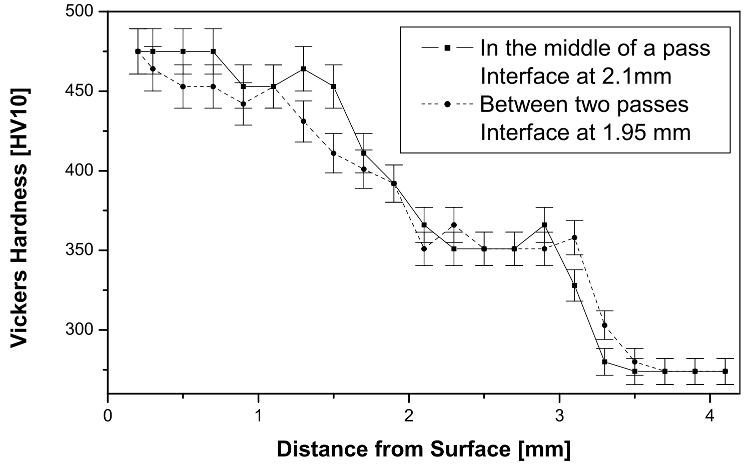

Fig. 1. Hardness evolution in the clad, HAZ, and the substrate along two symmetry lines

a width of about 6 mm. They were ground in the tensile direction down to paper size 2400. Two levels of total strain amplitude were employed, namely 0.4 and 0.6 %.

3 Results and Discussion

The microstructure of the substrate material consists of fine lamellar pearlite with some 10 % of ferrite in the previous austenite grain boundaries. Laser coating austenitised the closest underlying substrate, followed by formation of martensite. Later heating owing to the next parallel pass and to the second layer lead to tempering of the martensite, resulting in a microstructure of small carbides in a ferritic matrix, evenly distributed and also decorating previous austenite grain boundaries.

The hardness curves shown in Figure 1 demonstrate the variation of the hardness with respect to the depth under the surface. The clad shows declining hardness values inwards, reflecting grain coarsening and softening of the inner clad layer during application of the outer layer. The hardness plateau in the HAZ reveals a uniform carbide distribution. The short transition zone to the unaffected substrate material reflects a partial austenitisation in the first run. The slight differences of the two hardness profile positions indicate a difference in annealing influenced by succeeding passes. However, the hardness profiles through the coating and HAZ are fairly even over the whole layer.

Figure 2 shows stress-strain relations of cladded material in longitudinal and transversal direction and of substrate material for comparison. Apart from slightly different flow stress levels caused by different thickness of the cladded layer, the specimens exhibit no dependence on straining direction. However,

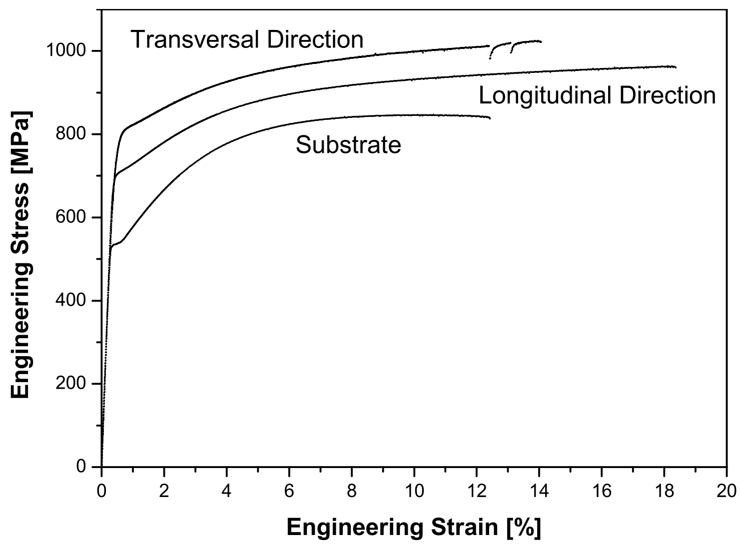

Fig. 2. Stress-Strain relations for cladded and substrate materials

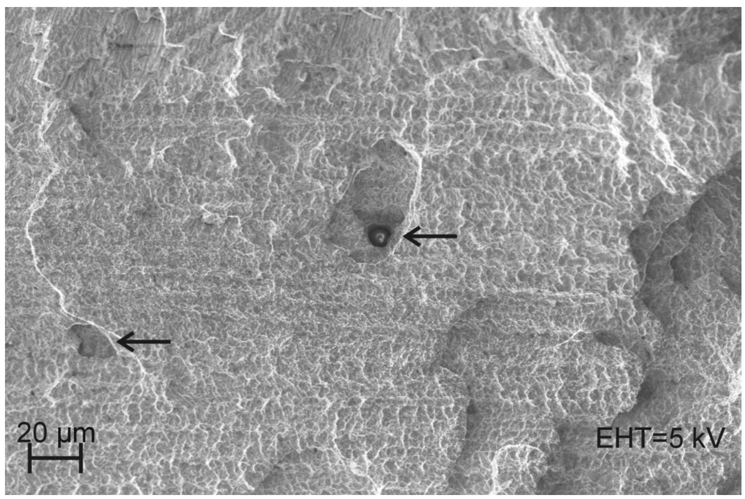

Fig. 3. Fracture surface from a transversal tensile test bar, showing an unmelted particle and pre-fracture (arrows)

the elongation to fracture turns out to be somewhat lower in the transversal direction. It is interesting to note that cladding leads to higher elongation to fracture compared with the substrate material. The fracture behaviour of the cladded material is essentially the same for both directions, i.e. the clad shows a brittle fracture (Fig. 3), the HAZ a ductile, and the unaltered substrate is in mixed mode, depending on local grain size and orientation. The only difference between the two fracture surfaces is the presence of small particles in the transversal fracture surface (Figure 3), initiating earlier fracture and, thus, lower elongation to fracture. The high elongation as well as the fracture surface topography reveal a good interfacial bond strength between the coated layer and underlying substrate material.

The fatigue tests with duplicate specimens in each case showed lifetimes of

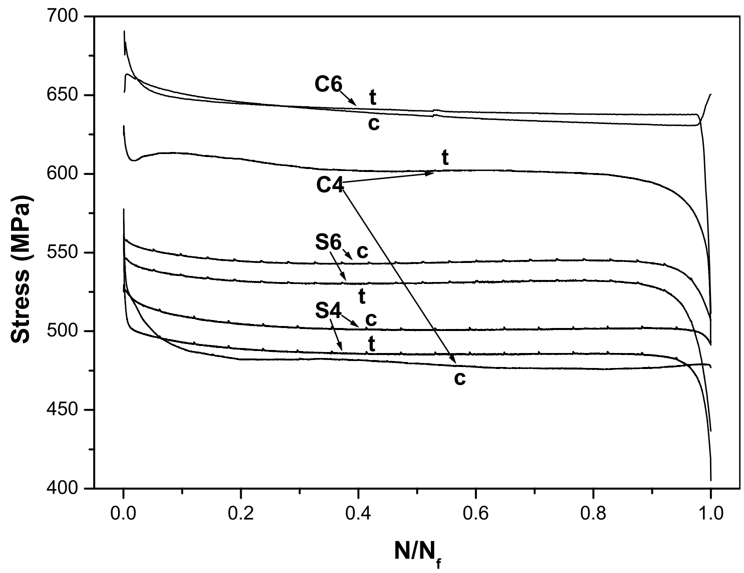

Fig. 4. Peak tensile (t) and absolute values of peak compressive (c) stresses of fatigue tests for the substrate (S) only and cladded (C) material, 4 and 6 indicate the strain amplitudes 0.4 and 0.6 % of the different curves respectively

$N_f = 10,000$ and $3,500$ at total strain amplitudes 0.6 and 0.4 % respectively for the substrate material. Cladded materials showed corresponding lifetimes of $N_f = 6,000$ and $1,500$. Obviously, the coating leads to some shortening of the lifetime, somewhat more pronounced at higher strain amplitudes. By normalising the lifetime, stress-lifetime diagrams as shown in Figure 4 can be drawn. Evidently, the stress levels are higher for the cladded material for the same strain amplitudes. A fairly limited softening takes place during strain cycling for all cases, independent of strain amplitude and material. While the substrate material exhibits essentially equal stress amplitudes in tension and compression, there is a very deviating picture for the the cladded material at the low strain amplitude 0.4 %. In this case, the highest peak stress levels are in the tensile direction and are much larger than the stresses in compression. This strong directionality in the peak stress levels vanishes for the strain amplitude of 0.6 %. As usually found in the this kind of fatigue behaviour representation, unloading due to cracking does not occur until after some 80 % of the whole lifetime. Such cracking leads to more unloading in tension than in compression.

The strong anisotropy in the peak stresses during cyclic straining of the cladded material at the low strain amplitude can qualitatively be understood as follows. Recent measurements of retained stresses (elastic strains) in a stellite laser coating (similar alloy) on austenitic stainless steels [4] revealed compressive stresses of the order of 80 MPa in the coating, while the underlying material had balancing but lower tensile stresses, which diminshed inwards into the material. This compressive stress in the coating corresponds to an elastic strain of approximately 0.04 %. In the present case, however, the martensite formation in HAZ leads to stress/strain reversal so that tensile retained stresses would result in the the surface coating. Further, considering the maximum elastic strain in the coating of about 0.5 %, it means that the imposed total strain amplitude of 0.4 % would slightly plastically deform the coating in tension while the compressive loading would not yield plastic straining. Therefore, the peak stresses would be higher in tension than in compression. On the other hand, a total strain amplitude of 0.6 % leads to plastic straining in both tension and compression with approximately similar peak stresses in both directions. Measurements of retained stresses/strains in the present case with accompanying analysis of the fatigue stresses are under planning in this project. The important issue, however, is the influence of retained strains on the the peak stess levels in tension and compression at strain amplitudes where the coating is only elastically deformed, but the substrate also plastically.

4 Conclusion

The interface region between the clad and the HAZ shows a good metallurgical bonding and thus, a high strength. The clad has a weakness zone between two subsequent passes, which could be solved by putting two subsequent passes closer together (partial overlapping). The cladded material shows only slightly shorter fatigue lifetimes than those of the substrate material, yet with considerably higher stress amplitudes. Internal stresses created during cladding causes asymmetry in the peak loads at small strain amplitudes.

Acknowledgements

The authors express their gratitude for the financal support of Duroc AB, which also cladded the steel plate. This work was performed within the centre of excellence Charmec (CHAlmers Railway MEChanics).

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