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Laser direct metal deposition for alloy development: use of nominal composition alloy powder as compared to mixed powder feeding with matched composition

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Abstract

In this work we test the feasibility of using the Laser Metal Deposition Process in the field of alloy development. Two powder blends are included in the powder feeding system, in independent hoppers, and mixed on-fly with weight mixing ratios as set by the user. Two mixtures were tested, Tribaloy 800+Ni and Tribaloy800+Ni20Cr, in proportions equivalent to the Tribaloy 900 composition. The microstructre of the mixed deposited material was compared with that of the nominal blend. Promising results were obtained with the first mixture (T800+Ni), while the second one (T800+Ni20Cr) rised questions to be considered about the entalphy of formation of the respective alloys and the relevance of using similar powder sized.

Keywords: Tribaloy, Laser Metal Deposition, Co-Ni Alloy.

1. Introduction

Laser direct metal deposition (LMD) with alloy powder feeding has proven to be successful in rebuilding worn components, producing weld overlays against wear, corrosion, oxidation as well as manufacturing of 3D parts. Based on laser fusion of blown powders, this technique also offers interesting possibilities in the field of alloy development. In principle, a wide variety of alloy compositions can be readably be achieved by mixing available commercial powders at different ratios. The fused and solidified material can then be

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studied in terms of phase composition and mechanical properties, Steen et al. 1992, Schwendner et al, 2000. , Collins et al., 2003.

In this work we analyzed the feasibility of that approach by using a commercial powder alloy, Tribaloy 900, and the mixture of two other alloys (Tribaloy 800+Ni and Tribaloy800+Ni20Cr) which, when mixed at adequate proportions, results in equivalent composition to the first one.

Tribaloy are a group CoCrMoSi alloys which own their outstanding properties against wear and corrosion at high temperatures to the precipitation of CoMoSi Laves phase. Different blends are available depending on the application requirements in terms of hardness toughness. The T800 composition guarantees the highest hardness values (up to 60HRC) in virtue of the larger amount of Laves phases ratio in the deposited material. However, being these phases brittle, it is very hard to weld by process as TIG,MIG or LMD, needing of heating temperatures as high as 500-600ºC. For these reason a new tougher blend, T900, was developed by basically adding Ni to the T800 composition. No great loss in wear and corrosion resistance properties are noted.

2. Experimental

A 2kW CW Nd-YAG laser unit was used for laser metal deposition. The laser systm is equipped with a Precitec four-jet YC30 cladding head for powder delivering onto the working surface. Powder feeding is made by use of a Sulzer TWIN-10C equipment comprising two hoppers with independent settings. Argon was used as shielding and powder carrier gas in all the experimental tests.

Four commercial alloy powders were employed, whose nominal chemical composition and powder sizes are summarized in Table 1. The first two are Co-base tribaloy powders: Tribaloy 900 and METCO 68F-NS with composition similar to Tribaloy 800. For the alloy mixing tests, a pure Ni (METCO 56F-NS) and a Ni20Cr blend (Metco 5640NS) were used.

In the tests, single laser scans were performed on austenitic AISI 304 stainless steel substrates. The laser was defocused to a diameter of 2.7 mm. The steel substrates were approximately 50x10 mm^2 size with 10 mm thickness.

After deposition, all samples were transversally cut, polished and etched for metalographic inspection. Some of the obtained samples were analyzed by SEM-EDX microscopy.

Table 1. Nominal chemical composition and powder size of alloys used in the study

Alloy Powder	Nominal Chemical composition (wt%)					Powder size (μm)
	Co	Ni	Cr	Mo	Si	
Metco 68F-NS (similar to T-800)	Bal.		17.5	28.5	3.4	-45+11
T-900 WM	Bal.	16	18	23	2.7	-180+53
Metco 56F-NS		99.5				-45+11
Metco 5640NS		Bal.	19.5			-125+45

3. Discussion of resuts

In order to obtain cladding beads with appropriate aspect ratio and minimal dilution several processing parameter sets were tested. Laser power was varied between 1000 and 2200 W, scan speed between 3 and

20 mm/s. The power flow rate was set between 2.7 g/min and 24 g/min depending on scan speed in order to obtain an uniform powder deposition per unit length of 15-20 mg/mm. Figure 1 shows a cross sectional view of a typical cladding bead profile.

After laser processing, the resulting microstructure by using either T800 or T900 is illustrated in Figure 2 a) and b) respectively. In both cases a dendritic pattern upon solidification is observed. They both correspond to the same set of parameters (3.6 g/l, P=1250 W and v= 3 mm/s). According to SEM-EDX measurements of elemental composition, the microstructure of T800 conforms to primary Laves phase dendrites (in white) within an interdentritic composed of Co-solid solution (in dark) and a fine lamellar eutectic of Co-solid solution and secondary Laves precipitates.

In the case of T900 , the increased amount of Ni results in an hypoeutectic solidification scheme: dendrites (in dark) of CoNi-solid solution as primary phase are observed with an interdendritic eutectic of Co-Ni solution and secondary Laves phases (white).

For the alloy mixing test, the T800 powder was input in one of the hoppers and the other was filled either with the pure Ni or the Ni20Cr powder blend. After calibration, suitable powder feeding rates were set in each of them so as to obtain in the mixture the nominal Ni weight percentage of the T900 alloy as shown in table 2. Nominal composition of T900 is included again for comparison purposes. Results obtained for the two alloy mixtures was as follows:

3.1. T800 (84%) + Ni (16%)

Figure 3 a) displays the microstructure obtained as compared to the one obtained by using T900 in the same conditions. The structure is homogeneous, in the sense that the same solidification pattern is found throughout all the deposited material. Elemental composition agree with expectations. It can be clearly noted that the addition of Ni has changed the original T800 alloy to one similar to the nominal T900, as both microstructures are equivalent. A slight difference can be appreciated in the dendritic/interdendritic ratio, being higher for the T800-Ni mix. Although not yet completely understood, this could be caused by the small differences in their respective composition or the somewhat higher degree of Fe dilution found in the mixed alloy (5% Fe as opposed to 2% in the T900 sample), as it is known that the Fe acts as a strong Ni-Co fcc stabilizer.

Microhardness was measured in the two material types. Reported results correspond to average of about ten measurements over the material sections. For the T900 a value of 593±45 HV was obtained, where as for the T800+Ni mix the result was 533±28 HV. Nominal hardness of the T900 blend, as given by the manufacturer is 52-57 HRC. Converting vickers values to HRC gives for the T900 a hardness in agreement with nominal, 52-56 HRC, while the T800+Ni mix is slightly lower, 50-53 HV. Reasons for this effect is the increased amount of soft-dendritic volume ratio and the disminished amount of Chromium in the resulting mixture, as this element acts as a solid solution strengthener.

Table 2. Weight percentage of alloy mixtures tested and corresponding elemental composition

Weight percentage in alloy mixture	Elemental composition (wt%)				
	Co	Ni	Cr	Mo	Si
T-900 (100%)	40.3	16	18	23	2.7
T800 (84%) + Ni (16%)	42.5	16	14.7	23.9	2.9
T800 (80%) +Ni20Cr(20%)	40,3	16	18	23	2.7

3.2. T800 (80%) + Ni (20%)

The main role of Cr in the Tribaloy alloys if providing corrosion resistance. Although not yet tested, it is expected that the T800+Ni mixture, due to the reduced Cr content, will lower the performance of the mixed alloy as compared to the original T900 one. Therefore a Ni20Cr blend was tested which, when combined with T800 in suitable proportions, precisely matches the composition of the T900 blend. Figure 3 illustrates the result obtained, which were the same despite the process parameter combination in terms of laser power and scan speed and powder flow rate. A quite inhomogeneous microstructure is achieved which reflects the unsuccessful mixing of the two alloys. Three distinct patterns are observed, denoted as A-B-C in the figure and whose elemental composition as measured by EDX is listed in Table 3. Region A and C correspond to the original dendritic and eutectic pattern of the T800 alloy, with a certain diffusion of Ni present. Region B corresponds to a hypoeutectic mixture with NiCo dendrites as primary phase, analog to the intended T900 estructure. However, due to the unefficient interdiffusion of elements in the material, the Ni content is two large leading to a large dentric/interdendritic ratio.

Reasons for the very different results as compared to the T800+Ni mixture could be errors on the powder flow rate calibration. In fact, the overall composition of the obtained samples gave a slightly reduced amount of Ni (i.e. 39Co14Ni19Cr25Mo3Si). However, these minor changes hardly seem to be the cause of such an inhomogeneous structure. Effects due to the negative entalphy of formation of the Ni20Cr matrix, which would imply an extra energy supply in the mixed material should be considered, as suggested by Collins et al, 2003. The effect of the different power sizes used in the mixture is another point to be investigated. The positive results obtained with the T800+Ni mixture, with equal powder sizes (see Table 1) would support this asumption.

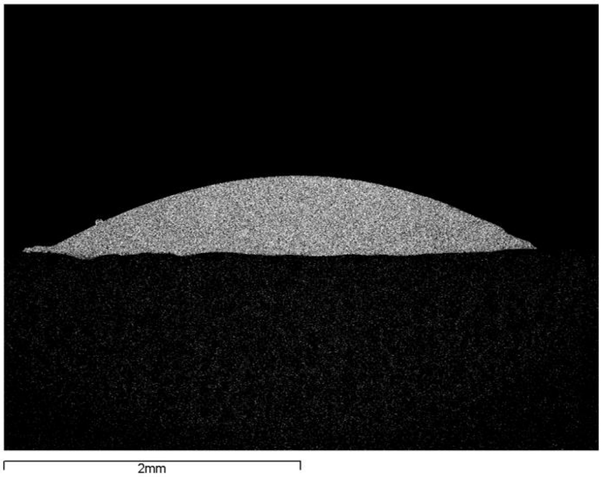

Fig. 1. (a) Cross sectional view of bead profile obtained with T900 (3.6 g/l) powder at P=1250 W and v= 3 mm/s .

Fig.2. Detail of microstructure after metal deposition as seen by SEM (retro-dispersed electrons): (a) T800 (b) T 900

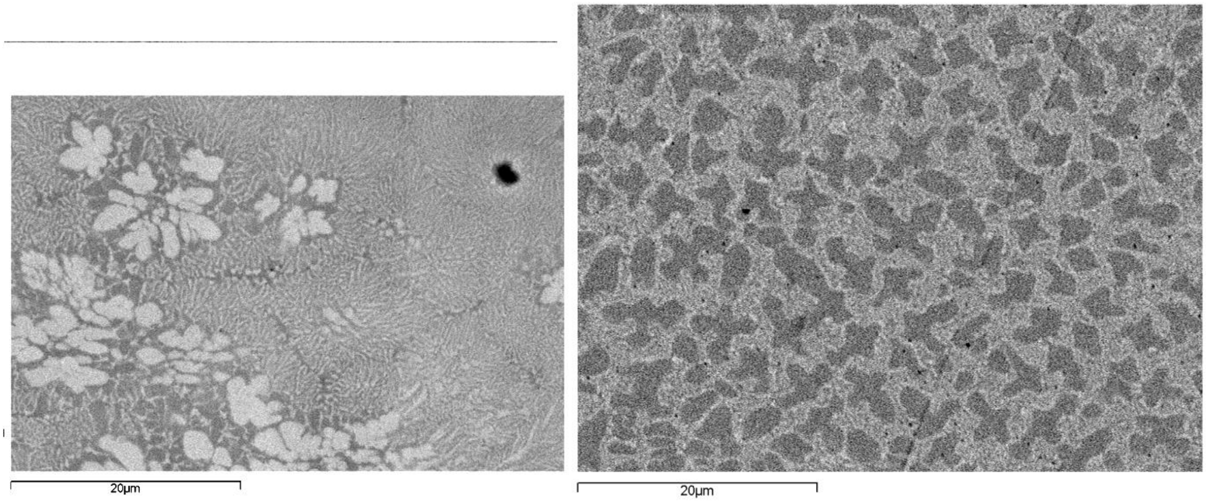

Fig.3. Detail of microstructure after metal deposition as seen by SEM (retro-dispersed electrons): (a) T800 (b) T 900

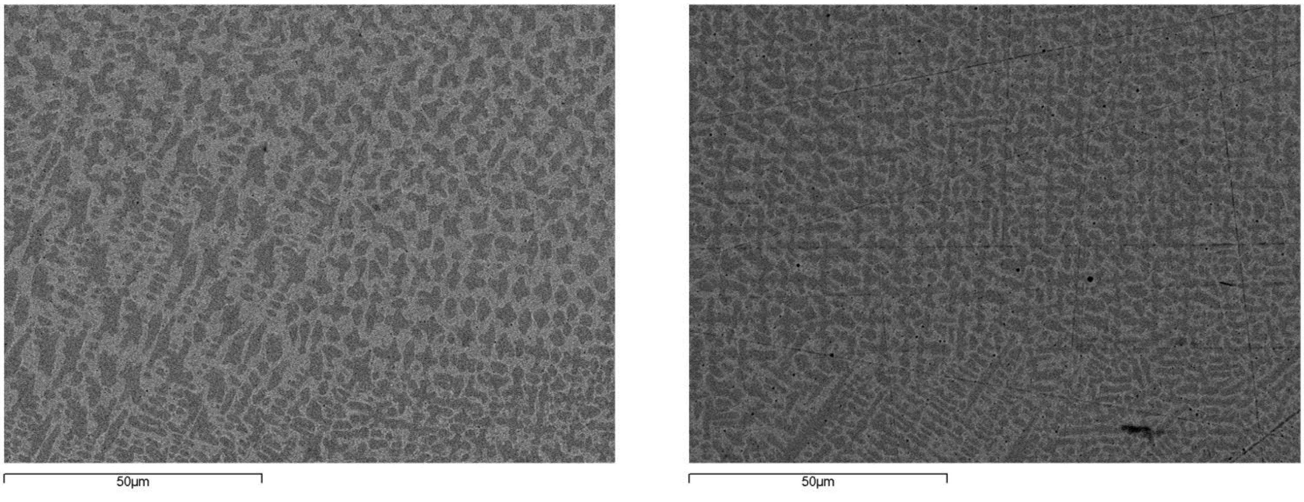

Fig.4. Microstructure of depostited T800+Ni20Cr mix as seen by SEM (retro-dispersed electrons).

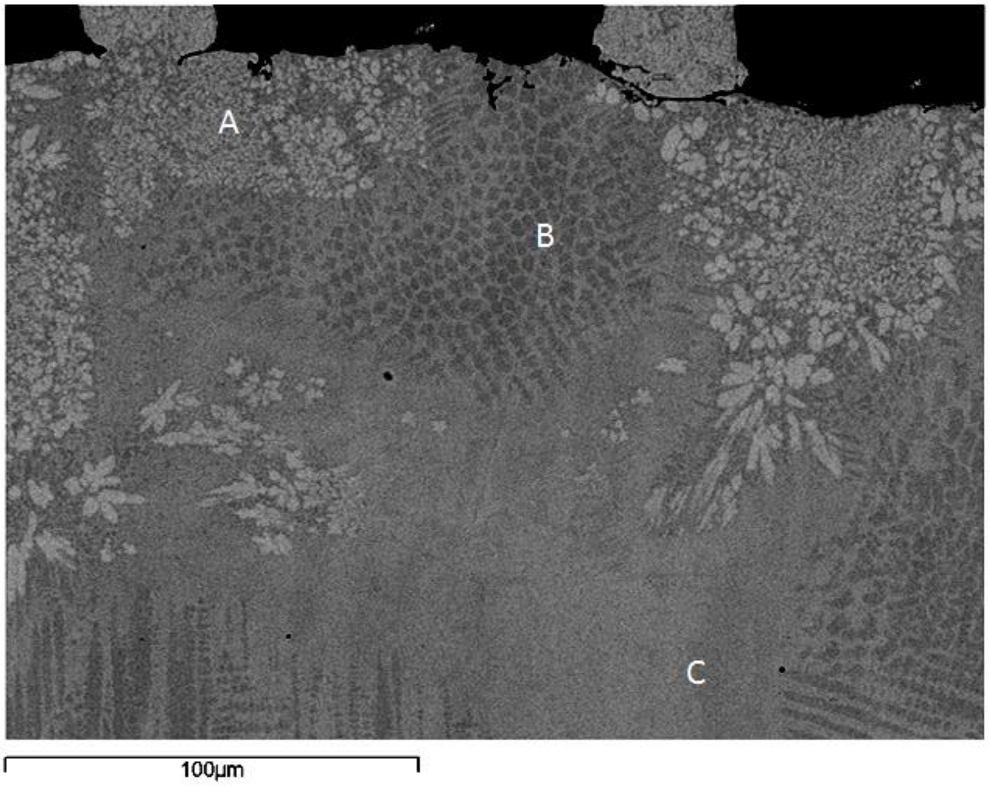

Table 1. EDX measurements of elemental composition of areas pointed in Figure 4.

	Elemental composition (wt%)				
	Co	Ni	Cr	Mo	Si
A	43.9	5.8	17.8	29.1	3.4
C	43.3	7.5	18.3	27.7	3.2
B	33.1	24.1	19	20.7	3

4. Conclusions

In this work we have tested the feasibility of using the Laser Metal Deposition process for alloy development purposes. Two different alloy mixtures ,T800+Ni and T800 +Ni20Cr, were employed in the laser deposition system in proportions equivalent to the T900 alloy. Comparison of the microstructure of the deposited T800+Ni material with the nominal T900 resulted promising results in terms of equivalent structure and hardness values. The analysis of the other tested mixture T800-Ni20Cr raised however some questions about the need to consider the respective entalphy of formation and the powder size of the alloy powders to be mixed.

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