Microstructure of laser cladded martensitic stainless steel

IIW Doc. IX-H-636-06

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Abstract

Laser cladding offers distinct advantages including low dilution, low heat input, less distortion, increased mechanical and corrosion properties excellent repeatability and control of process parameters. Solidification of laser cladded martensitic stainless steel is primarily austenitic. Microstructures consisting of martensite and retained austenite was obtained for 0.4C-13Cr (420) and 16Cr-2Ni (431). Almost fully austenitic microstructures were obtained for 0.4C-15Cr-5Ni (400 series) alloy. Materials expected to consist of a fully martensitic structure is proposed for laser cladding applications.

Keywords: Laser cladding, martensitic stainless steel

Introduction

Hardfacing of components with martensitic stainless steel overlays are commonly used in the steel manufacturing, mining and paper mill industries. Conventional arc welding processes usually result in microstructures consisting of martensite and ferrite. Delta ferrite lowers the hot cracking susceptibility but also reduce the strength, thermal fatigue and corrosion properties of the material. Lower heat input processes result in more delta ferrite [1]. Laser cladding of martensitic stainless steel offers distinct advantages including low dilution, low heat input, less distortion, increased mechanical and corrosion properties and excellent repeatability and control of process parameters. Solidification of laser cladded martensitic stainless steel is primarily austenitic and the final microstructure is dependant on the chemical composition and process parameters [2]. Lower heat input (increased speed or lower laser power) of a laser remelted 0.5%C, 13% Cr martensitic stainless steel resulted in an increase in retained austenite [4]. Higher fractions of retained austenite resulted in increased wear resistance of 0.5%C, 13%Cr materials at higher loads [5]. The purpose of this investigation is to determine the typical microstructure and hardness of laser cladded martensitic stainless steel for different process parameters. Hardfacing applications for these materials include continuous caster rolls, backup rolls, bearing journal areas and repair of martensitic stainless steel pump components.

Experimental procedure

Laser cladding of three different materials was performed on 10 mm flat bar C-steel substrate. A 4.4 kW Rofin DY044 diode pumped Nd:YAG laser coupled to a Kuka KR60L30 articulated arm robot and Precitec YW50 welding head with 300 mm focal length was used. Powder cladding was performed with Praxair Fe211-1 (420), Praxair Fe211-5 (400 series) and Metco 42C (431) powders. The chemical composition of the cladded layers, obtained with EDS is shown in **Table 1**. Process parameters were optimised for 1.5 and 4 mm bead width clad layers. Cladding of Praxair Fe211-5 and Metco 42C was performed with coaxial nozzles with powder focus diameters of 3.5 mm (Clad 1, 4.0 mm bead width, single layer) and 1.0 mm (Clad 2, 1.5 mm bead width, multiple layers). Cladding of Praxiar Fe211-1 was performed with an off axis nozzle and bead width of 6 mm. Process parameters are shown in **Table 2**.

Table 1 - Chemical composition of laser cladded martensitic stainless steel

Material	C*	Cr	Ni	Mn	Si	Mo	Ms (ºC)**
Fe211-1 (420)	0.4	13.6	0.02	0.71	0.65	0.02	100
Fe211-5 (400 series) Clad 1	0.4	14.97	4.97	1.15	0.44	0.35	-26
Fe211-5 (400 series) Clad 2	0.4	14.95	5.41	1.08	0.44	0.91	-36
42C (431) Clad 1	0.2	14.88	1.38	0.52	0.74	0.06	125
42C (431) Clad 2	0.2	16.1	1.84	0.31	0.45	0.13	81

*C-content of the powder
**Modified Ms temperature for laser cladding

Table 2 - Process parameters for coaxial and off axis powder cladding

Material	Laser power (W)	Speed (m/min)	Powder feed rate (kg/h)	Carrying gas (Flow rate l/min)	Stepover (mm)	Dilution (%)
Fe211-1 (420) Off axis	2500	0.6	0.6	He (3)	2.5	5
Fe211-5 (400 series) Clad 1	2500	1.2	0.6	Ar (10)	2	5
Fe211-5 (400 series) Clad 2	1500	3	0.3	Ar (5)	0.8	10
42C (431) Clad 1	2500	0.6	0.75	Ar (10)	2	10
42C (431) Clad 2	1500	3	0.4	Ar (5)	0.8	10

Praxair Fe211-5 (Clad 1 and Clad 2) and Metco 42C (Clad 1 and Clad 2) samples were subjected to post weld heat treatment @ 580ºC for 1 h. Metallographic evaluation and hardness testing was performed on as-welded as well as post weld heat treated samples. Scanning electron microscope analysis was also performed on the cladded samples to determine the chemical composition of the dendritic and interdendritic areas.

Results and discussion

Microstructures of Fe211-1 (420), Fe211-5 (400 series) and Metco 42C (431) are shown in **Figures 1 to 5**. The samples were etched with modified Fry's reagent. Microstructure of Fe211-1 **(Figure 1)** consists of martensite and interdendritic austenite. The microstructure of Fe211-5 **(Figures 2 and 3)** is almost fully austenitic. Post weld heat treatment @ 580ºC for 1 h revealed some martensite in the Clad 1(single layer) sample. Multiple layer cladding (Clad 2) of Fe211-5 resulted in fully austenitic structure with only some martensite in the first layer. Due to the dilution of 10% with the high speed (3 m/min) cladding, transformation of austenite to martensite occurred as a result of the increased Ms temperature. Why does the dilution increase the Ms temperature Microstructure of Metco 42C consists of martensite with some retained austenite.

None of the samples revealed delta ferrite after electrolytic etching with 10% NaOH @ 20V. This is contradictory to the typical microstructures obtained with arc welding of martensitic stainless steel. During rapid solidification of laser surface remelting or cladding, the primary solidification phase is austenite as shown in **Figure 6** [3]. As a result of the austenitic solidification, no ferrite is expected. Higher Cr-content of the cladding material might result in remaining liquid to solidify as ferrite due to enrichment of Cr in the interdendritic area. Alloys with more than 17% Cr will probably result in Cr enrichment in the interdendritic areas exceeding 19% and the remaining liquid to solidify is expected to solidify as ferrite (**Figure 7)**.

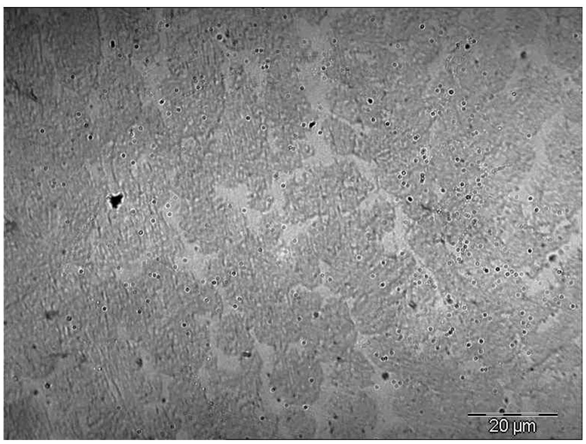

Figure 1 - Microstructure of Fe211-1 (420), as-welded, etched with modified Fry's reagent, 1000X

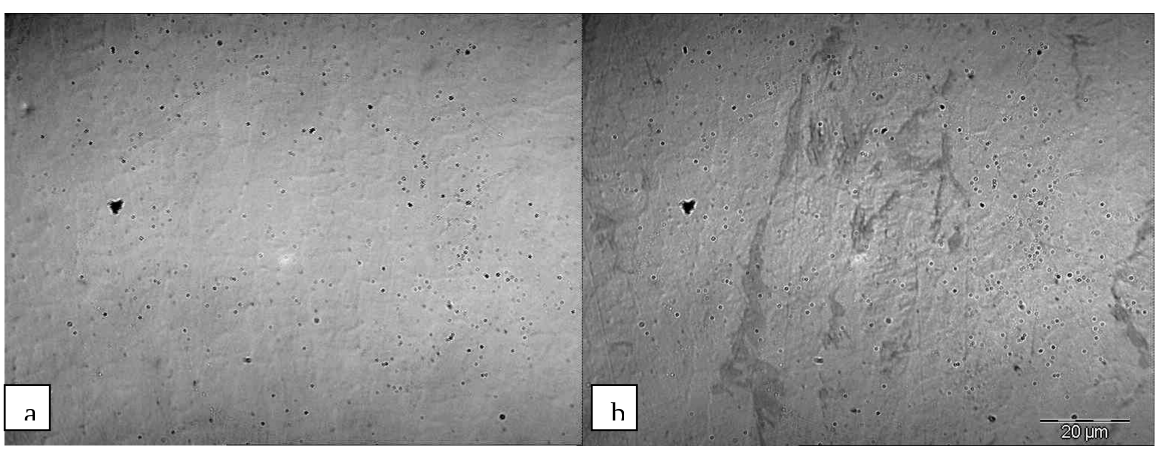

Figure 2 - Microstructure of Fe211-5 (400 series) Clad 1, etched with modified Fry's reagent, 1000X a) as-welded b) after PWHT @ 580ºC for 1h

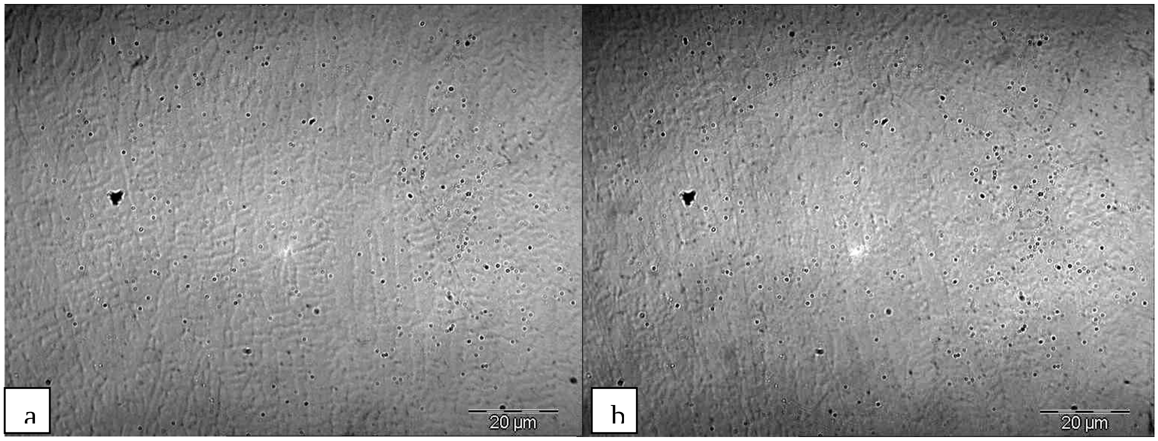

Figure 3 - Microstructure of Fe211-5 (400 series) Clad 2, etched with modified Fry's reagent, 1000X a) as-welded, b) after PWHT @ 580ºC for 1h

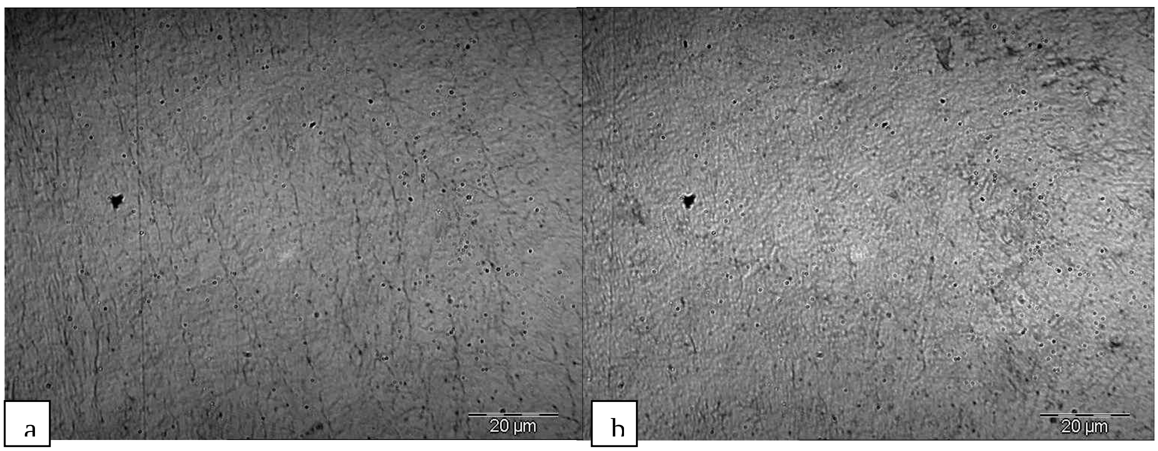

Figure 4 - Microstructure of Metco 42C (431) Clad 1, etched with modified Fry's reagent, 1000X, a) as-welded, b) after PWHT @ 580ºC for 1h

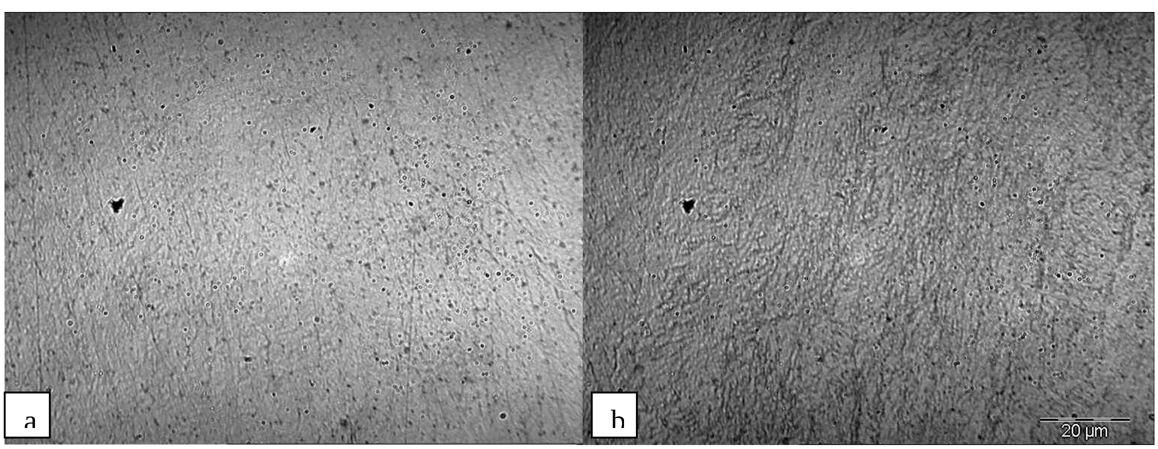

Figure 5 - Microstructure of Metco 42C (431) Clad 2, Etched with modified Fry's reagent, 1000X, a) as-welded, b) after PWHT @ 580ºC for 1h

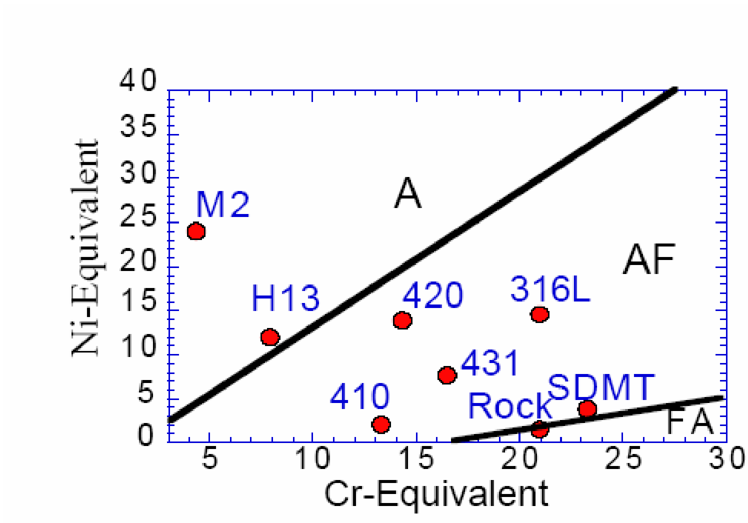

Figure 6 - Solidification mode for laser surface remelting [3]

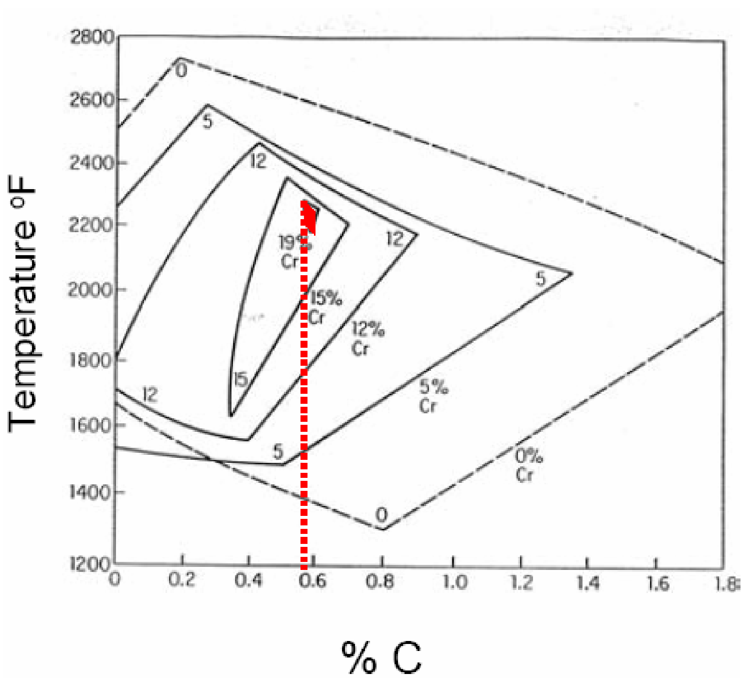

Figure 7 - Effect of Cr on austenite stability range in the Fe-C phase diagram

Shown in **Table 3** is the Cr-equivalent and Ni-equivalent of the laser cladded martensitic stainless steel according to the Schaeffler diagram where:

Ni-Eq = Ni + 30 C + .5 Mn (Eq 1)
Cr-Eq = Cr + Mo + 1.5 Si + 0.5 Nb (Eq 2)

Table 3 - Cr-equivalent and Ni-equivalent of laser claddded martensitic stainless steel

Material	Cr-eq	Ni-eg
Fe211-1 (420)	14	12
Fe211-5 (400 series) Clad 1	16	17.5
Fe211-5 (400 series) Clad 2	16.5	18
Metco 42C (431) Clad 1	16	7.5
Metco 42C (431) Clad 2	17	8

Laser cladded alloys plotted on the modified Schaeffler diagram is shown in **Figure 1**. According to the **Figure 6**, the predicted microstructure of Fe211-1 is martensite with retained austenite, that of Fe211-5 is predicted to be fully austenitic and the microstructure of Metco 42C is predicted to be martensitic with some retained austenite. This is in agreement with the results of the microstructural evaluation as shown in **Figures 1 to 5**. The amount of retained austenite was not determined. The amount of retained austenite predicted by the modified Schaeffler diagram is 57% for Fe211-1 and 27% for Metco 42C (431).

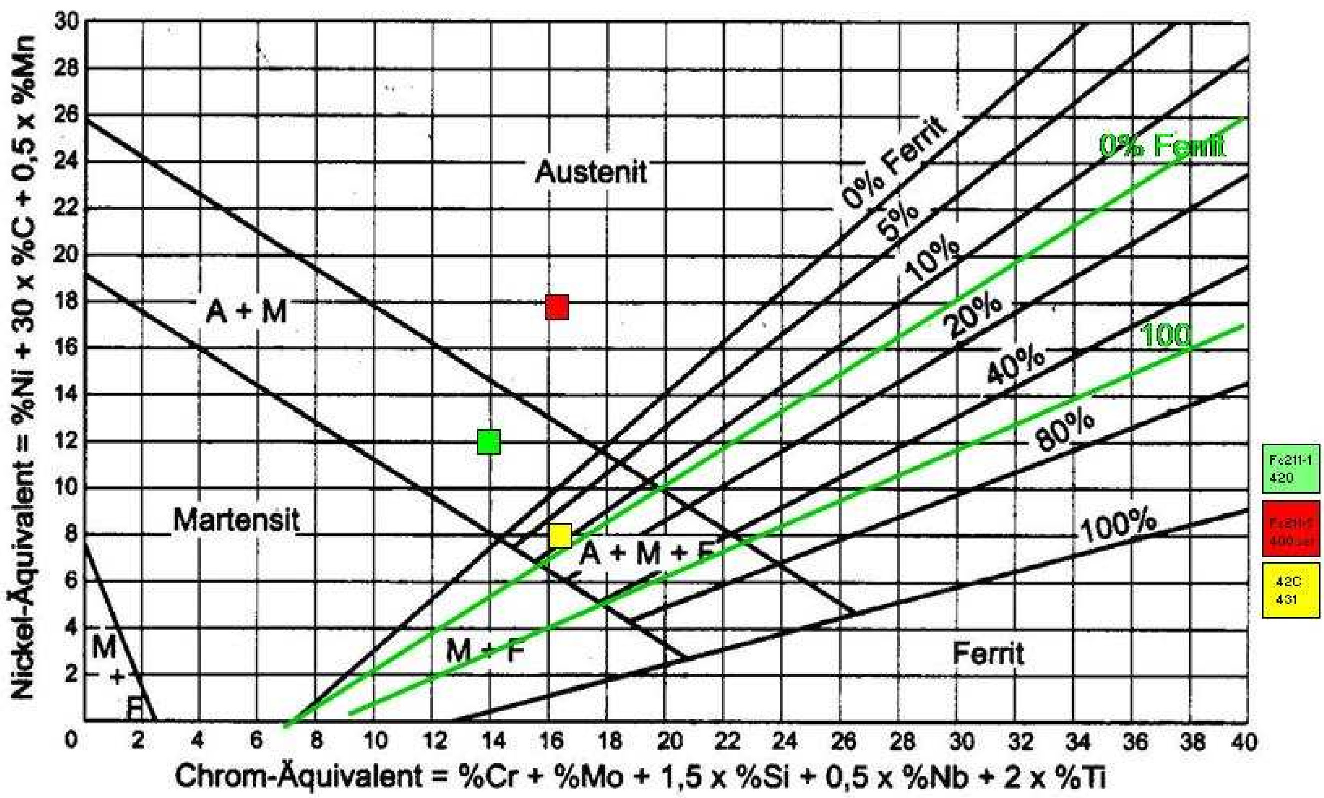

Figure 8 - Laser cladded alloys on modified Schaeffler diagram [2]

Shown in **Table 4** are the chemical compositions of the laser cladded martensitic stainless steel in the dendritic and interdendritic areas obtained by EDS. Enrichment of C, Cr and Mo occurred in the interdendritic areas as a result of austenitic solidification.

Table 4 - Chemical composition of the laser cladded martensitic stainless steel in the dendritic and interdendritic areas

Material	Area	C*	Cr	Ni	Mn	Si	Mo
Fe211-1 (420) Off axis	Dendritic	0.3	12.8	0.15	0.7	0.65	0.02
	Interdendritic	0.5	16.45	0.08	0.85	0.63	0
Fe211-5 (400 series) Clad 1	Dendritic	0.3	14.08	5.51	0.9	0.62	0.17
	Interdendritic	0.5	17.9	5.47	1.46	0.74	1.3
Fe211-5 (400 series) Clad 2	Dendritic	0.3	14.95	5.43	1.13	0.66	0.97
	Interdendritic	0.5	16.21	5.99	1.42	0.59	0.85
Metco 42C (431) Clad 1	Dendritic	0.1	13.43	1.69	0.32	0.47	0.27
	Interdendritic	0.3	15.63	1.44	0.6	0.62	0.35
Metco 42C (431) Clad 2	Dendritic	0.1	15.94	1.45	0.28	0.34	0.06
	Interdendritic	0.3	17.76	2.12	0.38	0.82	0.04

*Predicted C-content

The resultant Ms temperature in the interdendritic areas is therefore lower resulting in retained austenite in the interdendritic area. Ms temperatures for the dendritic and interdendritic areas were calculated using **Eq.3** for high alloy steels and are shown in **Table 4**.

$$Ms\ (^{\circ}C) = 550 – 350C – 40Mn - 20Cr – 10Mo – 17Ni – 8W – 35V – 10Cu + 15Co + 30Al \qquad (Eq\ 3)$$

Table 5 - Ms temperatures of laser cladded martensitic stainless steel

Material	Ms Dendritic area (ºC)	Ms Interdendritic area (ºC)
Fe211-1 (420)	158	10
Fe211-5 (400 series) Clad 1	32	-150
Fe211-5 (400 series) Clad 2	-15	-116
Metco 42C (431) Clad 1	215	104
Metco 42C (431) Clad 2	160	38

Hardness properties of the laser cladded martensitic stainless steel are shown in **Table 6**. The austenitic structure of Fe211-5 resulted in low hardness values (HV 250) and the martensite/austenite structure of Fe211-1 resulted in much higher hardness levels (HV 662). Hardness of HV710 was reported when cladding at slower speed with a 1.5 kW CO_2 laser resulting in 7% retained austenite [5]. Metco 42C resulted in high hardness (HV 573) due to little retained austenite. Post weld heat treatment @ 580C lowered the as welded hardness of Metco 42C to HD 354) due to tempering of the martensite. Post weld heat treatment of Fe211-5 (400 series) Clad 1 resulted in carbide precipitation on the grain boundaries (revealed after electrolytic etching with 10% oxalic acid) causing a decrease in the Ms temperature and resulting in martensite formation in these areas.

Table 6 - Hardness of laser cladded martensitic stainless steel

Material	Hardness, as-welded (HV1kg)	Hardness, PWHT (HV1kg)
Fe211-1 (420)	662	-
Fe211-5 (400 series) Clad 1	250	276
Fe211-5 (400 series) Clad 2	293	303
Metco 42C (431) Clad 1	577	354
Metco 42C (431) Clad 2	573	361

Proposed laser cladding martensitic stainless steel compositions are shown in **Table 7**. The predicted microstructure according to the modified Scheaffler diagram for Materials A and C almost fully austenitic and that of Material B is 10% ferrite, 45% martensite and 55% retained austenite. Due to the relative high Ms temperatures, almost fully martensitic structures are expected for Materials A and C and martensite with 10% ferrite for Material B.

Table 7 - Proposed martensitic stainless steel alloys for laser cladding

Material	C*	Cr	Ni	Mn	Si	Mo	Co	Ms (ºC)*	Cr eq	Ni eq
Material A	0.4	13	-	1	0.5	2.5	5.5	120	16.5	12.5
Material B	0.2	15	2	1	0.7	2.5	5.5	117	18.5	8.5
Material C	0.3	17	2	1	0.6	-	5	76	18	11.5

* Modified Ms temperature for laser cladding

Conclusion

Microstructure of laser cladding of martensitic stainless (0.4C, 13Cr) resulted in an austenitic martensitic structure. Increase in Ni content to 5% resulted in an almost fully austenitic structure. The microstructure of 16Cr-2Ni (431) consists of martensite with some retained austenite. Laser cladding of these materials did not result in delta ferrite due to the austenitic solidification mode of these alloys during rapid solidification. Ferrite is expected in alloys containing more that 17% Cr due to enrichment of Cr in the interdendritic areas during solidification.

References

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