Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 97 (2014) 1718 – 1723
Procedia Engineering
www.elsevier.com/locate/procedia

12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014

Effect of Heat Treatment on Hardness of Co-Cr-Mo Alloy Deposited With Laser Engineered Net Shaping

Mantrala Kedar Mallik[a], Ch. Srinivasa Rao[b] and Dr. V.V.S. Kesava rao[b]*

a. Asst. Professor, Vasireddy Venkatadri Institute of Technology, Guntur, A.P., India
b. Professor, AUCE, Andhra University, Visakhapatnam, A.P., India.

Abstract

The hardness of the samples fabricated with Co-Cr-Mo alloy powder using Laser Engineered Net Shaping process was tested. Three different process parameters (laser power, feed rate and scan speed) at two levels were used to fabricate the samples for L4 orthogonal array of Taguchi method. The hardness obtained was 446Hv with high laser power, low feed rate and high scan speed. With these process parameters, another set of nine samples were fabricated to apply heat treatment. Three heat treatment parameters (Solutionizing time, ageing temperature and ageing time) at three levels were used for L9 orthogonal array. The solutionizing timings were 30, 45 and 60 minutes at 1200^{o}C. One set from these nine samples was with no ageing and the other two sets were aged at 815 and 830^{o}C for 2, 4 and 6 hours. The test results of hardness have revealed that the samples aged with 830^{o}C for two hours have shown highest hardness (much more than the wrought material) but with much variance on the same surface. It has also been established by ANOVA that the solution time and ageing temperature have only a little effect on the hardness but the ageing time has considerable effect and prolonged ageing will result in loss of hardness.

Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014

Keywords: Co-Cr-Mo alloy; Micro Hardness; Laser Engineered Net Shaping; Solution Heat treatment; Ageing.

1. Introduction:

Co-Cr-Mo alloys have attracted the attention of the researchers because of their high resistance to wear and corrosion. The composition of alloying elements and the heat treatment applied play important role in the behaviour of the materials. The hardness of the material is highly affected by the percentage of carbon present in the alloy. Low carbon Co-Cr-Mo alloys are used as implants in medical fields being the material is bio-compatible. Many researchers have focussed on the study of wear properties of as cast Co-Cr-Mo alloy and its microstructure. The effect of heat treatment on wear resistance and microstructure was also studied. In almost all the cases the solution heat treatment followed by ageing was done for achieving better properties of Co-Cr-Mo alloy. Laser Engineered

* Corresponding author. Tel.: 9246400126
E-mail address: mallikkedar@yahoo.co.in

Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014
doi:10.1016/j.proeng.2014.12.323

Net Shaping (LENS^{TM}) is a layered manufacturing process in which the objects are deposited layer by layer as per the 3D model given to the LENS machine. Any complex objects can be fabricated using LENS process unless 3D model of the object cannot be done. The LENS machine is also capable of handling different metals like Titanium, Stainless Steel, Co-Cr-Mo, Zirconium and their alloys in powder form. Janakiram et al have studied the abrasive wear and microstructure properties of LENS deposited Co-Cr-Mo and found the material to be less resistive against abrasion. The present paper deals with the study of hardness of the LENS deposited Co-Cr-Mo alloy samples and the effect of heat treatment on the same.

2. Experimentation:

Commercially available Co-Cr-Mo alloy (Table 1) has been selected for analysis of the effect of heat treatment on hardness.

Table 1. Composition of Co-Cr-Mo powder in weight percentage.

Element	Weight Percentage
Cobalt	Bal.
Chromium	27.6
Molybdenum	5.6
Iron	1.4
Carbon	0.2
Sulphur	0.003
Boron	0.002
Manganese	0.6
Nickel	2.74
Phosphorus	0.004
Silicon	1.7
Tungsten	0.2

L4 orthogonal array of Taguchi method (Three process parameters at two levels) has been applied for fabrication of samples using Laser Engineered Net Shaping (LENS^{TM}), a rapid prototyping method for metals. The process parameters (Table 2) selected were, laser power (200W and 350W), Powder feed rate (5g/min and 10g/min) and Scan velocity (10mm/s and 20mm/s).

The powder has been deposited for five layers on a substrate of 5mm thick weld deposited plate. The surfaces of the deposits were polished with abrasive papers of grit size from 200 to 1000 followed by polishing with alumina powder for smooth surface. Positive Metal Identification (PMI) tests were conducted on all the four samples, powder and substrate using Bruker's XRF analyzer. Micro hardness tests at 200g load for 10 seconds have been conducted and results were recorded.

Table: 2: Parameters considered for sample fabrication. (L4 Orthogonal array of Taguchi method)

Sample Number	Laser Power (W)	Feed rate (g/min)	Scan velocity (mm/s)
P1	200	5	10
P2	200	10	20
P3	350	5	20
P4	350	10	10

The process parameters that were used for sample fabrication which has shown highest hardness were considered to be the best parameters for highest hardness. Using the same process parameters, another set of nine samples were fabricated. Now L9 orthogonal array of Taguchi method has been applied for heat treatment (Table 3).

Table 3. L9 Orthogonal array of Taguchi method for heat treatment

Sample Name	Solution treatment time in minutes (@ 1200°C)	Aging temperature in °C	Aging time In Hours
S1	30	No Ageing	
S2	30	815	4
S3	30	830	6
S4	45	No Ageing	
S5	45	815	6
S6	45	830	2
S7	60	No Ageing	
S8	60	815	2
S9	60	830	4

The solution heat treatment that has been carried out at 1200°C for 30, 45 and 60 minutes was followed by water quenching. Six samples were subjected to ageing at 830°C and 815°C for 2, 4 and 6 hours and three samples were taken without ageing [3-7]. All the nine samples were polished and tested for their micro hardness and the results were recorded. ANOVA (Analysis of Variance) has been applied on the hardness values to understand the effect of process parameters and heat treatment on the hardness since there are three factors for one response.

3. Results and Discussion:

The results obtained from the PMI and Micro hardness tests before and after heat treatment were tabulated and analyzed.

3.1 Positive Metal Identification: The PMI test results reveal that the composition of the LENS deposited samples does not vary much when compared with the powder. Among the samples tested, the sample deposited with high laser power, low feed rate and high scan speed has exhibited nearest composition of powder (Table 4A & B). The substrate which is a weld deposited plate has shown much difference with the powder.

Table 4A. Analysis of Positive Metal Identification.

Element	Powder	Substrate
Chromium	27.5	26.86
Nickel	2.83	2.45
Molybdenum	6.75	6.25
Tungsten	0.49	0.32
Cobalt	58.67	59.29
Iron	1.56	2.63
Manganese	0.50	0.85

Table 4B. Analysis of Positive Metal Identification.

Element	P1	P2	P3	P4
Chromium	27.24	27.55	26.89	27.27
Nickel	2.61	2.56	2.69	2.69
Molybdenum	6.08	6.05	6.12	6.17
Tungsten	0.39	0.40	0.39	0.45
Cobalt	60.00	59.96	58.37	59.92
Iron	1.65	1.47	3.54	1.43
Manganese	0.69	0.63	0.47	0.73

3.2. Micro Hardness: The hardness of wrought Co-Cr-Mo was identified as 432Hv from the literature [2]. Average of five readings was taken for calculating the Micro hardness of the LENS fabricated samples and the results with standard deviation are shown in the tables 5 and 6.

3.2.1. Micro Hardness Before heat treatment: The Micro hardness of the samples was observed to be uniform throughout the surface of the samples. All the four samples have shown the hardness compatible with the hardness of wrought Co-Cr-Mo but the substrate has shown very less. The samples fabricated with high laser power, low feed rate and high scan speed (P3) has shown highest hardness (446±2.87Hv) among the samples tested which is also higher than the wrought Co-Cr-Mo. The remaining three are just nearer to the wrought Co-Cr-Mo (Table 5). Hence it has been concluded that the samples P3 are the best samples for hardness and the process parameters were used for fabrication of second stage sample for heat treatment. The ANOVA results of percentage contribution of the process parameters have also established the same results (Fig. 1).

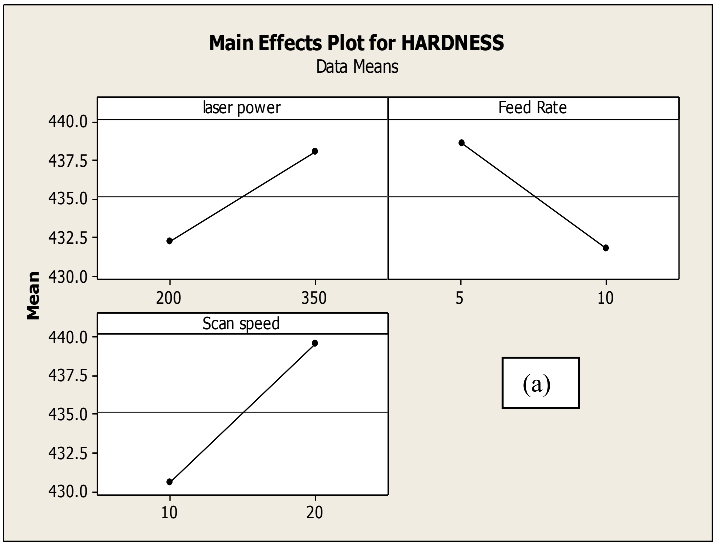

Fig. 1:(a) Main effects plot for hardnessprocess parameters

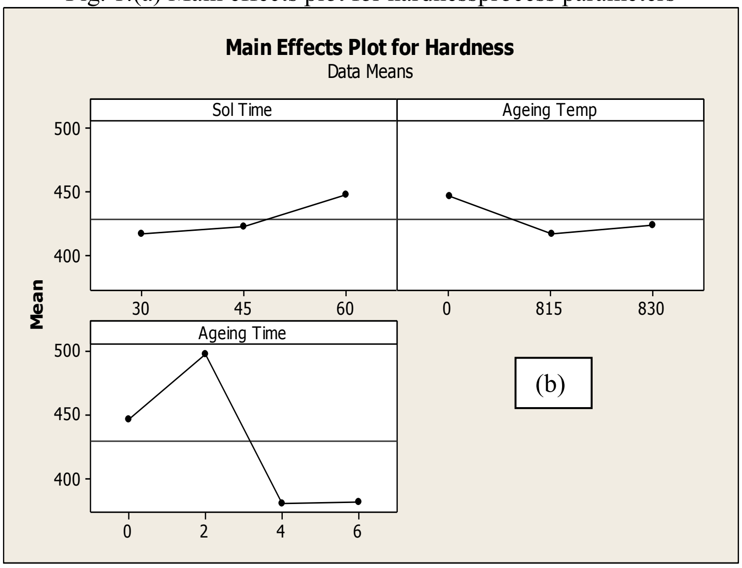

Fig. 1:(b)Main effects plot for hardness (b) Heat treatment

Table 5. Micro hardness results without heat treatment

Sl. No.	Sample Name	Hardness (HV)
1	P1	431±1.90
2	P2	433±5.17
3	P3	446±2.87
4	P4	430±4.48
5	Substrate	316±3.14

3.2.2. Micro Hardness after heat treatment: Even though the process parameters for fabrication of samples were same for all the nine samples of second stage, a lot of variance has been observed in the micro hardness of the samples due to the effect of heat treatment. Average of ten readings was taken to calculate the average micro hardness of the samples and the results with standard deviation values were shown in Table 6. The results reveal that highest hardness (518±69.41) has been obtained with samples with solution treatment with 1200^{o}C for 45min, ageing at 815^{o}C for 2 hours (S6). The main effects plot (Fig. 1) of ANOVA shows that the ageing time has maximum effect on the hardness and 2 hours solution time gives highest hardness. The other two parameters (solution time and ageing temperature) have less effect since the slope of the curve is very less i.e. there no much difference between minimum and maximum values. When these minimum differences are ignored, S6 will be the best for highest hardness. Some of the samples (S1, S7 and S8) have also shown higher hardness when compared with wrought and un-heat treated samples. The other heat treated samples have resulted in loss of hardness (S2, S3, S4, S5 and S9). The sample with solution treatment with 1200oC for 60min, ageing at 830oC for 4 hours (S9) has resulted in lowest hardness values. The standard deviation values are also high for many samples.

Table 6. Micro hardness results after heat treatment

Sl. No.	Sample Name	Hardness (HV)
1	S1	488±48.04
2	S2	368±22.77
3	S3	374±10.41
4	S4	344±20.52
5	S5	374±26.65
6	S6	518±69.41
7	S7	457±91.35
8	S8	471±32.58
9	S9	361±33.56

3.3 Discussion: The LENS fabricated samples before heat treatment have shown uniform hardness throughout the surface of the sample (low standard deviation values) whereas the samples after heat treatment have exhibited high differences in hardness not only among the samples but also in the same sample at different places (high standard deviation values). The sample (P3) fabricated with high laser power (350W), low feed rate (5g/min) and high scan speed (20mm/s) has shown highest hardness among the samples tested before heat treatment. Due to high rate of laser power available and high scan speed the material absorption rate is high in case of P3. The low feed rate also enables more absorption rate of the material during deposition. The more material absorbed, the more hardness resulted. The Table 7 shows the percentage of contribution of the process parameters on the hardness and all of them have considerable contribution. Hence the same process parameters were selected for fabrication of samples for heat treatment.

Table 7.ANOVA results of Percentage contribution of process parameters

Factor	Laser power	Feed rate	Scan Speed
Hardness	21.04 %	28.87 %	50.09 %

Table 8.ANOVA results of Percentage contribution of heat treatment parameters

Factor	Sol. Time	Ageing temp	Ageing time
Hardness	2.05 %	2.81 %	82.43 %

Ageing at high temperatures and prolonged times result in increase in other mechanical properties at the cost of hardness in Co-Cr-Mo alloys. It is expected that the hardness of the material increases after ageing, at the temperatures and times taken. Astonishingly the hardness values in most of the cases after ageing have decreased rapidly. But still S6 is aged only for 2 hours at 830^{o}C which has shown highest hardness. The Table 8 shows the percentage contribution of heat treatment parameters and only ageing time has highest contribution (more than 82%) whereas other parameters have very less. but the reason for high standard deviation is due to the repeated melting and solidifying of the samples during deposition itself as it was the layered deposition using laser. Whenever a new layer is deposited, the previous layers also get melted to absorb the material deposited as new layer. Thus the application of solution and ageing treatments has resulted in differences in the hardness values on the same surfaces of the samples.

4. Conclusions:

The conclusions drawn from the testing of hardness of LENS fabricated Co-Cr-Mo samples with and without heat treatment are as follows.

- The optimum process parameters for fabrication of samples for highest hardness (446±2.87Hv) of Co-Cr-Mo are high laser power; low feed rate and high scan speed whereas the hardness for wrought Co-Cr-Mo is 432Hv.
- The heat treatment has considerable effect on the hardness of the Co-Cr-Mo material.
- The highest hardness obtained with heat treatment is 518±69.41 with 1200^{o}C solution treatment for 45minutes and ageing at 830^{o}C for 2hours.
- Ageing time has highest percentage of contribution (82.43%) of effect on hardness .

References

[1]. Sang-Hak Lee, Eiji Takahashi, Naoyuki Nomura and Akihiko Chiba, "Effect of Heat Treatment on Microstructure and Mechanical Properties of Ni- and C-Free Co–Cr–Mo Alloys for Medical Applications" Materials Transactions, Vol. 46, No. 8 (2005) pp. 1790 to 1793

[2]. G. D. Janaki Ram, C. K. Esplin and B. E. Stucker, "Microstructure and wear properties of LENS deposited medical grade CoCrMo" J Mater Sci: Mater Med (2008) 19:2105–2111

[3]. Yoshimitsu Okazaki, "Effects of Heat Treatment and Hot Forging on Microstructure and Mechanical Properties of Co-Cr-Mo Alloy for Surgical Implants" Materials Transactions, Vol. 49, No. 4 (2008) pp. 817 to 823

[4]. Y. Bedolla-Gil, A. Juarez-Hernandez, A. Perez-Unzueta and E. Garcia-Sanchez, "Influence of heat treatments on mechanical properties of a biocompatility alloy ASTM F75" Revista Mexicana de f´isica s 55 (1) 1–5 may, 2009

[5]. Shingo Mineta, Shigenobu Namba, Takashi Yoneda, Kyosuke Ueda, and Takayuki Narushima, "Carbide Formation and Dissolution in Biomedical Co-Cr-Mo Alloys with Different Carbon Contents during Solution Treatment" Metallurgical and Materials Transactions A- volume 41a, August 2010—2129

[6]. H. R. Lashgari, Sh. Zangeneh and M. Ketabchi, "Isothermal aging effect on the microstructure and dry sliding wear behavior of Co–28Cr–5Mo–0.3C alloy" J Mater Sci (2011) 46:7262–7274

[7]. J.V. Giacchia, O. Fornaro and H. Palacio, "Microstructural evolution during solution treatment of Co–Cr–Mo–C biocompatible alloys" Materials characterization 68 (2012) 49 – 57