Impact Strength and Fracture Analysis of Co-Cr-Mo Alloy Deposited with Laser Engineered Net Shaping – An Additive Manufacturing Technology

Mantrala Kedar Mallik[a*], K. L. Narayana[b]

Abstract - **Co-Cr-Mo alloy is the best bio-compatible material with high strength so far known. Medical grade Co-Cr-Mo alloy is widely used in orthopedic implantation and dentistry. Knowledge of the mechanical properties will enable the manufacturers to fabricate the medical components exactly to fit the requirements. Evidently customized components can be comfortably made by additive manufacturing technologies. Laser Engineered Net Shaping is one such technology which deposits metallic materials layer by layer to fabricate the required components. In the present investigation to find the behavior of the Co-Cr-Mo alloy when deposited with Laser Engineered Net Shaping some samples are fabricated and tested. Laser power, powder feed rate and the laser scan speed are the process parameters selected and optimized by primary metallurgical analysis of the samples. With the best parameters identified, laser power (350W), powder feed rate (5g/min) and laser scan speed (20mm/s) samples are deposited as per the ASTM standards. All the samples are tested for the impact strength and the results are tabulated. Fracture analysis has been carried out on the samples after testing. It has been identified that the samples of Co-Cr-Mo alloy deposited with Laser Engineered Net Shaping have shown brittleness in impact strength.**

Key words: Impact strength; Additive Manufacturing; Laser Engineered Net Shaping; Co-Cr-Mo alloy; Brittleness; Process parameters.

I. INTRODUCTION

Most often the components or machine parts are subjected to impact or sudden loading in industries. Sometimes the surgical implants may also undergo such situation. The knowledge of the impact strength of the material will help the design and production engineers to select appropriate material for the applications they require.

Development of new materials and new processes also contribute in fulfilling the increasing needs of the industry. Co-Cr-Mo alloy was identified to be the biocompatible material which has high mechanical strengths. The material has attracted the attention of researchers because of release of C and Ni ions into the blood when used as surgical implant. Later Co-Cr-Mo alloy with low C and Ni content (ASTM 75) was developed to serve the needs of biomedical applications [1]. As the Co-Cr-Mo alloy has high mechanical strengths, it is also used in industries where high wear and corrosion resistances are highly desirable. Metallurgical characterization was carried out on the as-cast samples for its micro structure analysis, hardness and wear resistances [2]. Consequently experiments were conducted on the material by applying the solution and ageing heat treatments [3-5].

Vamsi et al. [6-7] have experimented on Co-Cr-Mo alloy in combination with Ti6Al4V, deposited with Laser Engineered Net Shaping (LENS) an additive manufacturing technology which facilitates fabrication of components directly from the CAD models or MRI/CT Scan data. The LENS process uses energy dispersion technique for fabrication of samples from the powder. Artificial hip joints were fabricated with different porosities and the samples were tested for bio compatibility etc.

Mallik et al. [8-10] have used LENS and weld deposition processes for fabricating and characterizing Co-Cr-Mo alloy samples. The influence of process parameters on microstructure, hardness, wear and corrosion resistances was studied. L4 orthogonal array of Taguchi method was used and the process parameters selected for sample fabrication were laser power (200W and 350W), powder feed rate (5g/min and 10g/min) and the laser scan speed (10mm/s and 20mm/s) each at two levels. The results revealed that high laser power, low powder feed rate and high scan speed are desirable for high hardness, high wear resistance and high corrosion resistance.

From the literature it has been observed that no much attention was paid to find the impact strength of LENS deposited Co-Cr-Mo alloy. The current experimentation is an attempt to find the impact strength and analyze the same.

a. First (Corresponding) author: Dr. M. Kedar Mallik, Associate Professor, Department of Mechanical Engineering, Vasireddy Venkatadri Institute of Technology, Nambur, Guntur Dist. A.P. India. +91 92464 00126, kedarmallik@gmail.com
b. Second author: Dr. K. L. Narayana, Professor & Dean (R&D), Koneru Lakshmaiah Education Foundation (Deemed University), Vaddeswaram, Guntur Dist., A.P. India. drkln@kluniversity.in

II. EXPERIMENTATION

Commercially available Co-Cr-Mo alloy (Kennametal Stellite) powder is used for depositing the samples for impact testing as per the standards (ASTM E23-07A) with Laser Engineered Net Shaping process (Optomec Inc., Albuquerque, New Mexico). The length of the specimen is 55mm and the cross sectional area being 10 X 10mm^2. The working material (here Co-Cr-Mo alloy) in the form of powder is fed through nozzles on to a substrate of the same material where a thin beam of laser melts the powder and deposits layer by layer. The platform on which the substrate is fixed moves along X and Y directions (both horizontal) and the Z direction movement (vertical) is by the nozzle head. Oxygen level in the deposition chamber is maintained as less than 10ppm by continuous circulation of argon gas through the chamber to avoid oxidation of the alloy. The input was given by .STL file generated from CAD model of the specimen. The process parameters selected are from the previous experimentations and are shown in Table 1. These parameters were identified as best for high hardness, high wear resistance and high corrosion resistance among the samples tested [8].

It is well known that the weaker section lies in Z direction, between the consecutive layers of deposition, the samples are deposited such that the length is in Z direction. Because of the spillover in deposition, the samples have rough surface which are polished for a smooth surface and a 'V' notch is cut with an angle of 45^{O} (Fig.1) as per the ASTM standards of E23-07a.

TABLE I
PROCESS PARAMETERS FOR SAMPLE FABRICATION

Process parameters	Value
Laser Power	350W
Powder feed rate	5g/Min.
Laser scan speed	20mm/s

Fig. 1: Impact test specimens fabricated using Laser Engineered Net Shaping as per ASTM Standards

Using the Charpy impact testing method, keeping the sample horizontal, the samples are tested for their impact strength and average of 10 samples are recorded. The fractured samples are tested under electron microscope for any defects and the results are analyzed.

III. RESULTS AND DISCUSSION

The results obtained from the impact testing of the LENS deposited Co-Cr-Mo alloy samples are shown in Table 2. No much variation is observed in the values of impact strength among the samples tested. The impact strength values obtained from the tests are considered as very low. Generally, the deformation of the samples under test causes resistance against the impact load before fail. The low values of the readings indicate that the samples did not deform and are referred to be brittle. The flat broken surface and the microscopic observation of the samples after fracture also indicate the same (Fig. 2).

TABLE II
RESULTS OF IMPACT TESTING ON LENS DEPOSITED Co-Cr-Mo ALLOY

Sample No.	Impact strength (J)
1	44
2	40
3	42
4	43
5	44
6	45
7	42
8	43
9	45
10	42
Average	**43**

By nature the LENS deposited Co-Cr-Mo alloy samples are hard, high wear resistant and high corrosion resistant. The microstructure analysis of the samples reveals that the grains formed during deposition are lamellar type and the boundaries are observed to be uniform and evenly spaced as shown in Fig.3.

Fig. 2: Fracture of LENS deposited Co-Cr-Mo alloy specimens under impact testing

ISBN: 978-988-14048-6-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

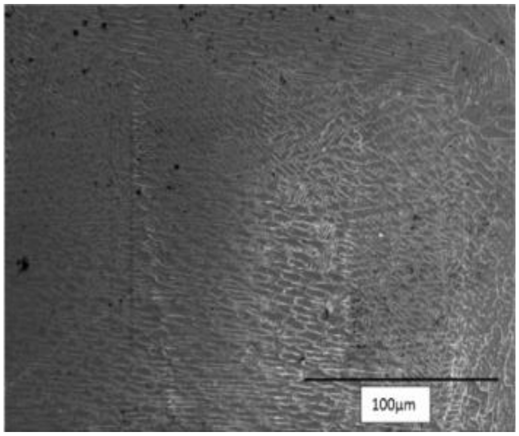

Fig. 3: Microstructure of LENS deposited Co-Cr-Mo sample [8].

Also as the deposition is by complete melting of the powder by laser with very low heat affected zone, the carbides ($Cr_{23}C_{16}$) formed, are along the grain boundaries which are brittle in nature [8]. Evidently all the samples have exhibited brittleness under impact testing.

IV. CONCLUSIONS

The conclusions drawn from the experimentation on impact strength of Co-Cr-Mo alloy, deposited with Laser Engineered Net Shaping are as follows.

Because of simplicity in the method and smallness in the specimen size, Charpy impact test is used widely for toughness evaluation of the materials. The test is generally performed on specimens without pre-cracking. However, one can obtain information from the test on an absorbed energy. From the present experimentation on impact strength of Co-Cr-Mo alloy deposited with Laser Engineered Net Shaping, the flat broken surface of the specimens with no plastic hinge indicate brittle fracture behavior of the material, which is also evident from the achieved low impact strength values.

REFERENCES

[1] J.V. Giacchi, C.N. Morando, O. Fornaro, and H.A. Palacio: Microstructural characterization of as-cast biocompatible Co–Cr–Mo alloys. Mater. Charact. 62, 53 (2011).

[2] L.C. Julian and A. Munoz: Influence of microstructure of HC CoCrMo biomedical alloys on the corrosion and wear behavior in simulated body fluids. Tribol. Int. 44, 318 (2011).

[3] 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

[4] C. Balagna, S. Spriano , M.G. Faga Characterization of Co-Cr-Mo alloys after a thermal treatment for high wear resistance" Materials Science and Engineering: C, Vol. 32, n. 7, pp. 1868-1877, 2012

[5] R. Rosenthal, B. R. Cardoso, I. S. Bott, R. P. R. Paranhos, E. A. Carvalho "Phase characterization in as-cast F-75 Co–Cr–Mo–C alloy" J Mater Sci (2010) 45:4021–4028

[6] B.V. Krishna, W. Xue, S. Bose, and A. Bandyopadhyay: Functionally graded Co-Cr-Mo coating on Ti-6Al-4V alloy structures. Acta Biomater. 4(3), 697 (2008).

[7] F.A. España, V.K. Balla, S. Bose, and A. Bandyopadhyay: Design and fabrication of CoCrMo based novel structures for load bearing implants using laser engineered net shaping. Mater. Sci. Eng., C 30(1), 50 (2010).

[8] Kedar M. Mantrala, Mitun Das, Vamsi K. Balla, Ch. Srinivasa Rao and V.V.S. Kesava Rao Laser-deposited CoCrMo alloy: Microstructure, wear, and electrochemical properties, J. Mater. Res., Vol. 29, No. 17, Sep 14, 2014, pp 2021-2027

[9] Mantrala Kedar Mallik, Chalamalasetty Srinivasa Rao, Vaddi Venkata Sundara Kesava Rao, "Effect of heat treatment on hardness and wear behavior of weld deposited Co-Cr-Mo alloy", Revista Materia, Vol.20, No.2, 2015, pp 542-549

[10] Ganzi Suresh, K.L. Narayana and M. Kedar Mallik, "A Review on Development of Medical Implants by Rapid Prototyping Technology", International Journal of Pure and Applied Mathematics Vol. 117, No. 21, 2017, pp 257-276