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ScienceDirect

Procedia Manufacturing 30 (2019) 581–587

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

14th Global Congress on Manufacturing and Management (GCMM-2018)

Sliding Wear Reliability Studies of Inconel 625 Components Manufactured by Direct Metal Deposition (DMD)

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Abstract

Direct Metal Deposited (DMD) specimens using Inconel 625 were tested for sliding wear and analysed for reliability. In this study, Taguchi's experimental techniques were used to develop L9 orthogonal array using Design of Experiments (DOE). Three different process parameters, coating thickness, load and temperature were selected for manufacturing the components. Sliding wear test was carried out and wear properties was investigated. Two-parameter Weibull method was used for the reliability studies by which reliability was estimated for different wear values of the manufactured components. The distribution plot on reliability was considered as a good design for Weibull analysis. The study shows that Weibull distribution method can be used for describing the distribution of times to wear properties of rapid prototyped components using DMD for functional applications.

Keywords: Sliding Wear; DMD; Weibull

1. Introduction

Direct metal deposition (DMD) is a promising technology by which metallic components can be manufactured and also repair works done with ease by layered manufacturing method. In the field of rapid manufacturing and development, DMD plays a major role in re-fabrication of engineering components. Many research studies have been carried out to compare the mechanical properties of components manufactured by RP process and conventional methods. DMD process also helps in the manufacturing of complex shapes and reduces the lead-time in product development. There are many advantages in using metal based additive manufacturing processes for industrial and

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10.1016/j.promfg.2019.02.082

other engineering applications. Metals in powder form are used to manufacture and experimental studies are reported. Direct metal laser sintering (DMLS) of Al Si 10 Mg for analyzing the microstructure and the mechanical properties is studied and increase in compressive strength and micro- hardness is reported [1].

A comparative study between the wear characteristics of DMLS and conventionally manufactured bush were studied and it was observed that DMLS components showed better wear resistance [2]. Studies using laser direct deposition for repair application on turbine air foils was carried out by a semi-automated geometric reconstruction algorithm. This method is very much useful in remanufacturing and repair application [3]. A recommended optimal parameters for DMD of Inconel 718 super alloy on an Inconel 718 high temperature alloy during a heat treatment study as, scanning speed of 5. 8 mm/s, powder feed rate of 6.45 g/min, laser power of 650 W and beam diameter of 1 mm [4]. For a study on coating thickness and surface roughness on tribological properties of TiN films on steel substrates, there was an increase in wear of the counter facing steel with increase in coating thickness. Wear resistance showed better results when coating thickness was increased [5]. Wear studies on DMD components manufactured using H13 tool steel deposited on mild steel with different process parameters like applied load, temperature and coating thickness showed that as load increases, coefficient of friction decreases. Further observations revealed that porosity along the wear track at various locations [6].

Design of experiments using Taguchi technique to find out the most influencing parameter on wear properties for specimens manufactured by DMD using Inconel 625 coating on mild steel is reported. Test results showed that applied load was the significant influencing parameter on wear and co efficient of friction [7]. Thermal fatigue properties were studied on H13 tool steel coated on copper by DMD process. It was observed that, two types of cracks were formed on the surface of the coatings. Also studies on H13 coated with 316 stainless steel were carried out and compared. Results show that less number of cracks were observed for H13 tool steel coated with 316 stainless-steel compared to directly coated H13 tool steel [8]. Reliability studies using Weibull method for DMLS components for fatigue [9] and tensile strength [10]. Taguchi's experimental designs [11] combined with optimal process parameters were used for testing the specimens. Weibull distribution method applied to the test results shows that this method can be used for analyzing the failure times on fatigue and tensile strength of DMLS components. Moreover these results help in manufacturing components for functional application.

There are different wear mechanisms by which failure occurs in functional components and abrasive wear is the dominant one. Components manufactured through additive manufacturing are found to be better in improving frictional and wear properties. Limited studies on wear has been carried out and reported on DMD components. The wear properties and reliability of the same has to be investigated. Weibull distribution, a statistical method is widely used in analysis of reliability. This method helps in describing the distribution of failure times [12]. This paper attempts to carry out a reliability analysis on wear properties of DMD manufactured Inconel 625 components using Weibull distribution method so that the components can be used for functional application.

2. Materials Processing and Testing

2.1. Material Processing

Mild steel was chosen as the substrate material and Inconel 625 was coated over it by DMD process. The 105D DMD machine was used for coating of the samples, which has a capability to control the process parameters using a closed loop system. From a hopper, the material is fed to a coaxial nozzle. Laser is used to heat and melt the material. Thus, a metal pool is generated by the heat generated by the laser and the metal fuse together. Argon and Helium mixture is used as shaping and shielding gases. Nine mild steel samples were prepared and Inconel was coated with three different thicknesses as 0.5, 1 and 1.5 mm and made ready for wear testing as per the standards. The manufactured specimen with different coating thickness is shown in Fig.1.

2.2. Wear Testing

Ducom TR-285 M9 wear testing machine was used for testing the DMD specimens. Testing was carried out in high frequency reciprocating wear test rig with a stroke length of 15mm. A 3 parameter 3 levels L9 orthogonal array was chosen for the experiments on a ball-on-disc wear test configuration. Test duration and frequency was set as 2 hrs and 10 Hz respectively. Test parameters were set and wear depth, coefficient of friction and temperature were acquired continuously. The test parameters and results are shown in Table 1.

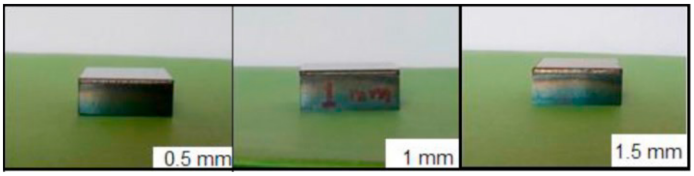

Fig.1. Wear Testing Specimens

Table 1. Wear Test Parameter and Results

Experiment	Thickness (mm)	Load (N)	Temperature (ºC)	Wear Depth(μ)
1	0.5	20	35	6.7160
2	0.5	50	100	10.177
3	0.5	80	150	12.434
4	1	20	100	7.1320
5	1	50	150	11.993
6	1	80	35	13.637
7	1.5	20	150	6.5390
8	1.5	50	35	9.7120
9	1.5	80	100	15.332

3. Results and Discussions

3.1. Reliability Analysis

Wear of DMD components is influenced by many factors, the alloy combination, grain size and manufacturing process parameters. For statistical analysis of wear test results, data consist of endurances of a sample of test specimens at a constant test conditions. By means of histogram, graphical representation of the distribution of endurances can be shown. A smooth curve known as frequency distribution curve can be replaced with histogram for large population of specimens. The Weibull analysis used here to access the reliability is closely approximated to log normal distribution [12]. Wear depth obtained from the testing of the DMD components were taken for the reliability analysis. Initially, the design values were calculated for the reliability studies for wear and shown in Table 2. Wear depth values were sorted from lowest to highest and are presented in Table 3, with the corresponding experiment numbers. Next step was to find out the design values for wear depth.

Table 2. Design Values for the Weibull Analysis

Trials	Mean Rank	1/1-Mean Rank	ln ln [1/1-Mean Rank]
1	0.074468085	1.080459770	-2.5589408343
2	0.180851064	1.220779221	-1.6119943817
3	0.287234043	1.402985075	-1.0829294225
4	0.393617021	1.649122807	-0.6926602670
5	0.500000000	2.000000000	-0.3665129139
6	0.606382979	2.540540541	-0.0700181697
7	0.712765957	3.481481481	0.2211078264
8	0.819148936	5.529411765	0.5365410102
9	0.925531915	13.42857143	0.9545050490

Table 3. The Weibull Analysis Design Values for Wear Depth

Trials	Experiment	Wear Depth(μ)	*f*(t)
1	7	6.539	0.000642344
2	1	6.716	0.000673544
3	4	7.132	0.000745864
4	8	9.712	0.001067891
5	2	10.177	0.001085707
6	5	11.993	0.001004009
7	3	12.434	0.000950784
8	6	13.637	0.000760735
9	9	15.332	0.000456424

Different values, namely ln of wear depth, the Weibull cumulative distribution function with respect to time. Which is given by F(t) = 1 － exp [− (t/ θ)m], 0 ⩽ t < ∞, where ‘ θ ’ is the scale parameter and ‘m’ is the Weibull shape parameter. The Weibull shape parameter is tabulated and scale parameter was calculated from value of ‘c’ as θ = e(c/m). The value of ln of wear depth were plotted against ln ln [1/1-Mean Rank] to get the Weibull probability plot of failure times as shown in Fig. 2.

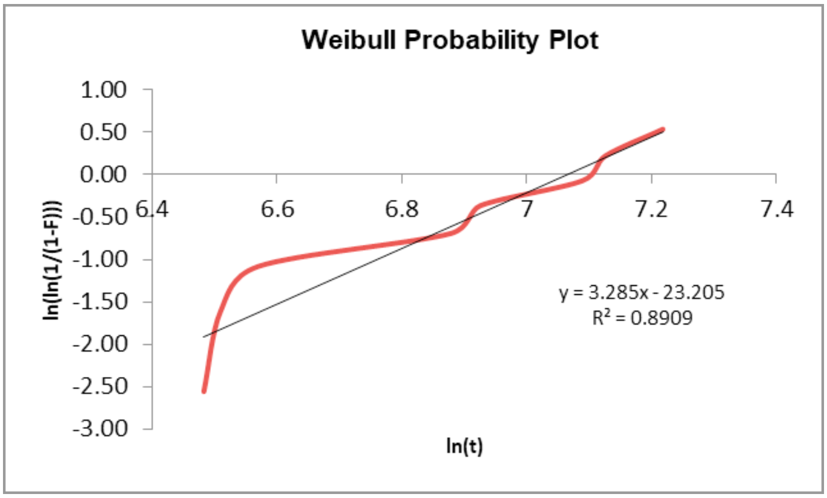

Fig. 2. The Weibull Probability Plot for Failure times for Wear Depth

From this graph, the curve approximated as a straight line and the equation obtained was taken as y=3.285× –23.205. Where, values of slope, m=3.285 and y-axis intercept, c=23.205. The value of coefficient of determination (R^2) obtained is 0.8909, which is closer to unity and considered as a straight line. The Weibull shape parameter (m) obtained is greater than unity and indicates an increase in wear rate as per Weibull analysis. Value of scale parameter θ is obtained as 1169.026863. To get the Weibull distribution plot, the calculated value of f(t) is plotted against scale parameter θ. Fig. 3 shows the graph which resembles the standard Weibull distribution plot. It may be noted that the density function rises sharply in the beginning followed by a flattening and a peak later. This behaviour is nearly similar to a log normal distribution.

For different values of wear depth, the Weibull survival probability was calculated and is shown in Table 4. The reliability level corresponding to a certain wear depth was also calculated and is shown in Table 5. From the table, the reliability levels of wear depth of components manufactured by DMD with selected processing parameters and testing conditions will survive 99 percentage for a wear depth of 2.88μ. The calculated values of reliability are plotted against wear depth and are shown in fig. 4.

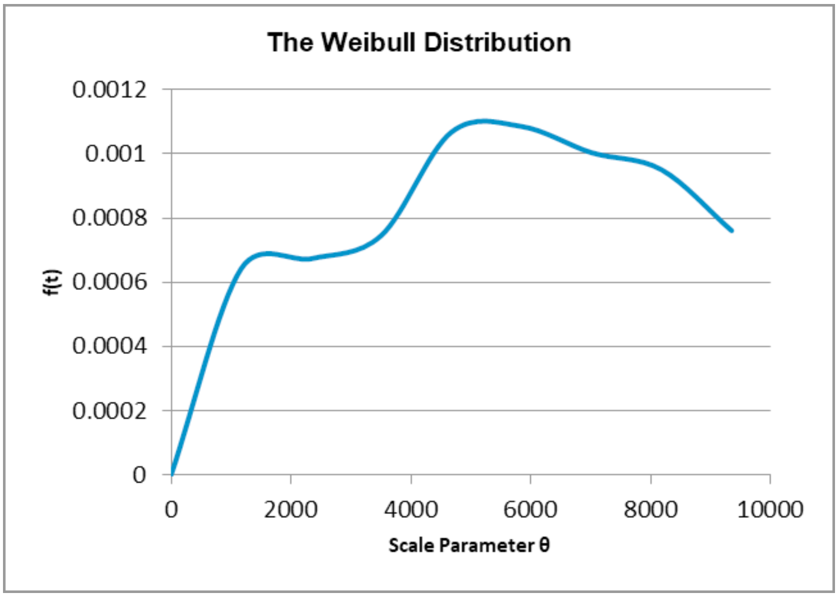

Fig. 3. The Weibull distribution plot for Wear depth

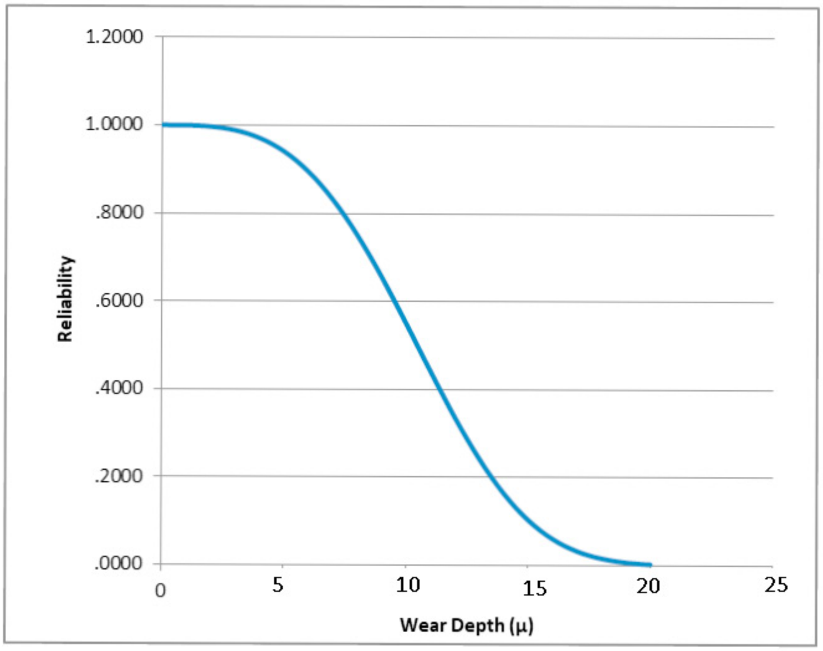

Fig. 4. Reliability Graph for Wear Depth

Table 4. The Weibull Survival Probability for Wear Depth

Wear Depth(μ)	Survival Probability	Reliability
1.00	.0003	.9997
1.50	.0012	.9988
2.00	.0030	.9970
2.50	.0063	.9937
3.00	.0114	.9886
3.50	.0189	.9811

Table 5. Reliability and Wear Depth

Reliability	Wear Depth (μ)
0.01	18.61
0.1	15.07
0.5	10.46
0.9	5.89
0.99	2.88

From the graph it is observed that the wear depth is increased when the reliability is decreased. From the results, it is inferred that wear depth of components is higher as the load applied during testing is increased. Thus, value of shape parameter (m) has great influence on reliability.

4. Conclusions

Wear testing was evaluated for Inconel 625 components coated by DMD on mild steel substrate. Studies on reliability using Weibull analysis shows that the Weibull distribution plot can be considered as a good design for prediction. Reliability levels of wear depth of components with the selected processing parameters and testing conditions will survive 99 percentage for a wear depth of 2.88μ. Hence the reliability was found to be better for wear depth of 2.88μ. The Weibull distribution method can be used for obtaining the distribution of time duration to wear of additive manufactured components using DMD for functional applications.

Acknowledgments

We would like to thank the Central Manufacturing Technology Institute (CMTI), Bengaluru, India for their support to manufacture the DMD test samples and the Vellore Institute of Technology for providing us the facility to carry out the wear testing.

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