Influence the Sliding Wear Behavior of WC-12Co Coated Stainless Steel on Tool Life Prediction under High Velocity Oxy-fuel

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Abstract: This objective of this study was to analyze the influence of WC-12Co coated SUS 400 stainless steel coatings on wear volume under sliding wear testing and to predict the tool life of WC-12Co. These WC-12Co specimens were passed the high velocity oxy-fuel (HVOF) sprayed coating and used to carry out the wear experiments under sliding wear behavior by the wear testing apparatus base on ASTM G133 standard. The Taylor's equation was used to calculate the tool life prediction model. After that, the simulation of Monte Carlo method was used to estimate the tool life under several applied load (10-50 N). Finally, the applied load was influencing the tool life of WC-12Co coated SUS 400 stainless steel coatings.

Key words: High velocity oxygen fuel (HVOF), wear volume, tool life, prediction.

1. Introduction

The tool life prediction model is an important capability to productivity and dependable machining data which both important data can lead to optimal the tool life, minimal production costs and manufacturing efficiency [1]. Previously, several researchers used the Taylor's equation as an empirical methodology for the tool life prediction models. There have been many researches of predicting tool life model in the Taylor's equation namely; the mechanics models, dynamics models and tribology models [2]-[4]. This investigation leading to such functions was long term and requires many material resources. The studies concerning sliding wear behavior of the materials have been extensive and widely reported [5]-[8]. Varieties of possible tool life modelling approaches for uncertainty systems have been developed over the last decades. The sampling-based through Monte Carlo simulation method is the most multipurpose and widely used because of its general applicability and typical robustness. Karandikar *et al.* applied the Taylor's equation in combination with the Monte Carlo simulation method for the tool life prediction model of carbide tool for turning MS309 steel work material [9] and Srisattayakul *et al.* calculated the tool life equation of fishing net-weaving machine component from Taylor's equation the simulated the tool life graph of fishing net-weaving machine component from Monte Carlo simulation method [10].

Thermal sprayed coating was used extensively in a variety of applications. There are many thermal spray processes available to date: the HVOF sprayed coating, which uses higher exhaust velocities and lower flame temperatures than other coating processes. HVOF sprayed coating can operate coatings of low porosity levels. Numerous researches have been performed on WC-Co based coating [11]-[13]. WC-Co based coatings were widely practiced in a variety of industrial applications as machining tool, extrusion die, compression mold, etc., due to their superior chemical combination of fracture toughness, surface roughness and hardness properties [14]-[17]. Among others, the WC-12Co coatings is one of the best choices for mechanical parts due to its intelligence wear resistance properties. HVOF sprayed WC-12Co coatings improved the wear resistance of mild steel under dry sliding conditions [18]. Moreover, it has been exhibited to compare with other materials [12], [19], [20].

In this study, the influence the sliding wear behavior of WC-12Co coated SUS 400 stainless steel on wear volume under high velocity oxygen fuel (HVOF) sprayed coating was investigated. The results of work, the tool life model of WC-12Co coated SUS 400 stainless steel using Taylor's equation and Monte Carlo simulation method, respectively.

2. Experimental Procedure

The finished surface specimens were prepared the average surface roughness (Ra) of 6 μm with silicon carbide (SiC) abrasive papers. HVOF sprayed coating of WC-12Co micro-structured powders on SUS 400 stainless steel was operated by the SULZER METCO DIAMOND JET machine (as shown in Fig. 1) which the optimization of HVOF parameters such as fuel/oxygen ratio of 16-19 l/min per 250-290 l/min [21-23], the powder feed rate 98-116 g/min [24] and the spraying distance 250-298 mm, as shown in Table 1.

Fig. 1. HVOF sprayed coating of WC-12Co by SULZER METCO DIAMOND JET machine.

Table 1. Parameters of WC-12Co Coated SUS 400 Stainless Steel on HVOF Sprayed Coating Process

Deposition parameter	Value
Oxygen flow	250-290 l/min
Propane flow	16-19 l/min
Powder feed rate	98-116 g/min
Spraying distance	250-298 mm

The sliding wear behavior of the WC-12Co coatings were investigated using a pin-on-flat wear testing machine under un-lubricated conditions. In the experiment of the sliding wear testing, the WC-pin (cylindrical of Ø 2.5 mm) was tested in a sliding wear apparatus, such as ASTM G133 standard [25]. The wear tester apparatus is shown in Fig. 2. Environment of sliding wear testing were controlled temperature of 20oC and relative humidity of 50%. The specimens (dimension of 25×50×3 mm) were subjected to the sliding wear test condition were applied load range of 20 N and 40 N, a sliding velocity of 200 rpm, a stroke length of 15 mm and continuous sliding distance range of 1000 to 5000 m with 5 replicates in each test condition. These parameters of sliding wear behavior of the WC-12Co coatings were presented in Table 2. The results of wear volume after passed the sliding wear testing can show in Table 3.

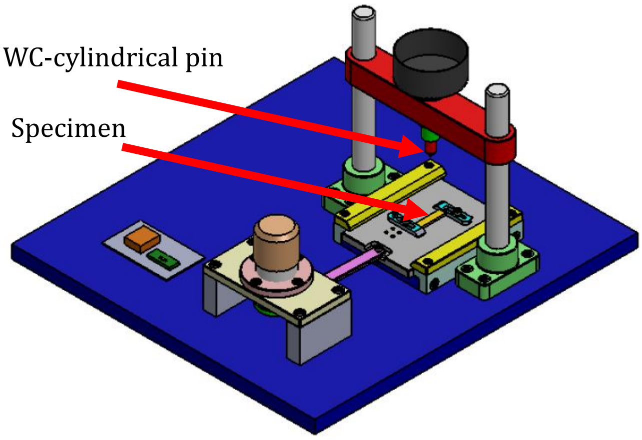


Fig. 2. Sliding wear testing machine.

Table 2. Parameters of Sliding Wear Testing

Wear testing parameter	Value
applied load	20 and 40 N
sliding distance	1000, 2000, 3000, 4000 and 5000 m
sliding velocity	200 rpm
stroke length	15 mm
Temperature	20^{o}C
Humidity	50%

Table 3. Sliding Distance Corresponding to the Wear Volume Values at the Level of 30 mm^2 of WC-12Co

Applied Load	Sliding Distance (m)				
(N)	1000	2000	3000	4000	5000
20	4.0471	8.89	12.9919	21.9454	31.0344
20	4.0121	8.9502	12.9726	21.9369	30.9726
20	3.9842	9.0118	13.0134	22.1082	30.9858
20	4.0661	8.9185	13.1003	21.9566	30.9426
20	3.9769	8.948	12.9986	22.0405	31.0048
40	8.1043	17.9027	26.0525	44.011	62.0343
40	8.0157	17.8745	25.9784	43.9116	61.9911
40	7.9534	17.8062	26.0164	43.9708	61.9919
40	8.1866	17.7332	26.043	43.8351	62.0042
40	8.1238	18.101	26.1198	43.7221	62.1524

3. Result of Experimental

The wear volume was used to characterize the influences of WC-12Co on the wear volume under sliding wear testing with the time range from 1000 to 5000 m. The wear volume of the specimen has a major negative effect on the surface and the quality of the mechanical when the wear volume reaches a certain level of 30 mm^3. The wear volume of WC-12Co was plotted as a function of sliding distance with applied load range of 20 N and 40 N, which is illustrated in Figure 3. It was noted that wear volume increased with the increase of applied load for WC-12Co.

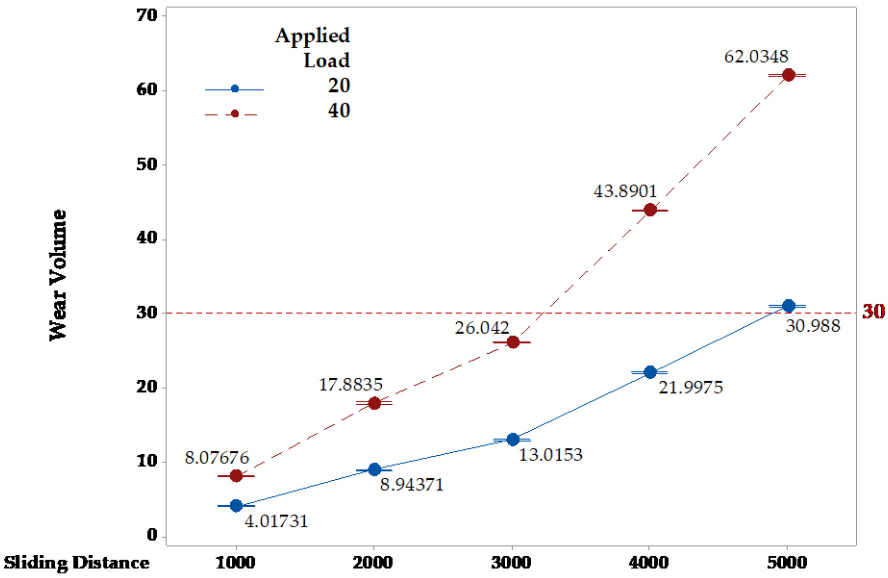


Fig. 3. Average wear volume versus sliding distance of WC-12Co.

The different wear volume of the two applied loads can be estimated to a tool life model. Tool life model was obtained from Taylor's equation based on the results of the wear volume as the function of sliding distance with applied load range of 20 N and 40 N. The basic Taylor's equation was developed to relating life of the hook to the main wear experimental parameter (i.e., applied load) shown in Equation (1) [26]. In literature [27], [28], considerable studies were reported on relationship between the machining process with tool life.

$$L\,(T)^{n} \quad = \quad C \tag{1}$$

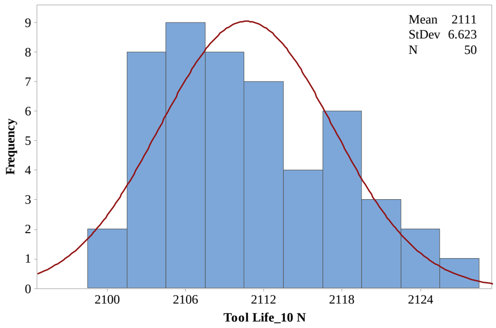
where T is the tool life (m), L is the applied load (N). Furthermore, n and C are the tool life coefficient of the specimen, whose values depend on sliding wear testing conditions. The tool life model of WC-12Co modified by the Taylor's equation were formulated with logarithm technique as Equation (2). After that, the coefficient of the model was calculated based on the modified Taylor's equation. Therefore, the tool life model of WC-12Co was obtained as Equation (3) and (4), respectively.

$$n \log T - \log C \quad = \quad -\log L \tag{2}$$

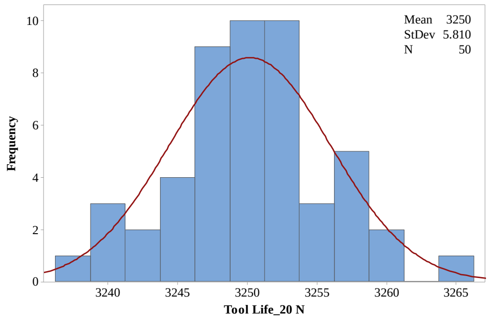
$$L\,(T)^{-1.6089} = 0.00004475 \tag{3}$$

$$T = \left({}^{0.00004475}\!/_{L}\right)^{-1/1.6089} \tag{4}$$

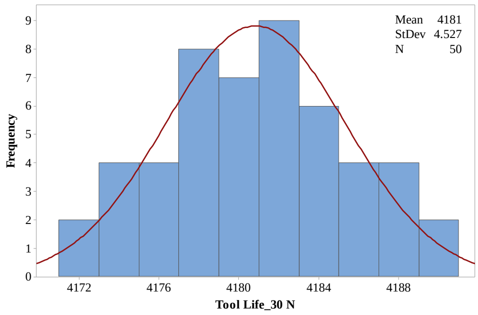
After that, the variation of WC-12Co tool life model can be achieved by using a Monte Carlo simulation. The Monte Carlo method applied the principle's normal distribution by specifying the mean and variation for input at a confidence level of 95 %. The five-levels of applied load range (10 N, 20 N, 30 N, 40 N and 50 N) were defined as the input to generate sampling data set for each applied load. Each level of applied load created the sampling data set of 50 that followed normal distribution which these data were investigated the statistical at a confidence level of 95% (as shown in Fig. 4). Finally, the result of the Monte Carlo simulation for the tool life models of WC-12Co is presented in Fig. 5. The limitation of WC-12Co tool life model were exhibited the 5743.97 m, 5000 m, 4180.83 m, 3250.19 m and 2110.67 m at applied load at 10 N, 20 N, 30 N, 40 N and 50 N, respectively.



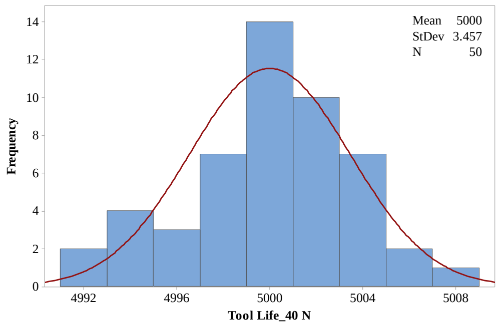
(a) Histogram of tool life 10 N.



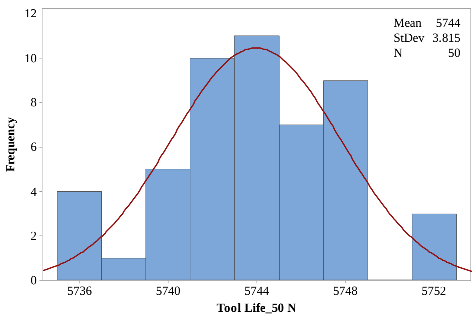
(b) Histogram of tool life 20 N.



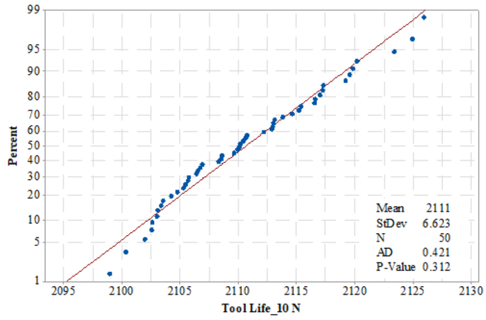
(c) Histogram of tool life 30 N.



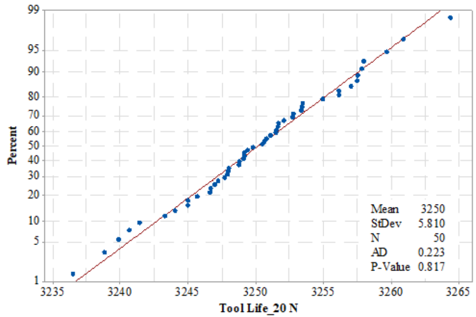
(d) Histogram of tool life 40 N.



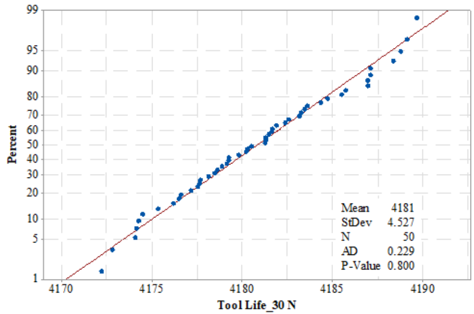
(e) Histogram of tool life 50 N.



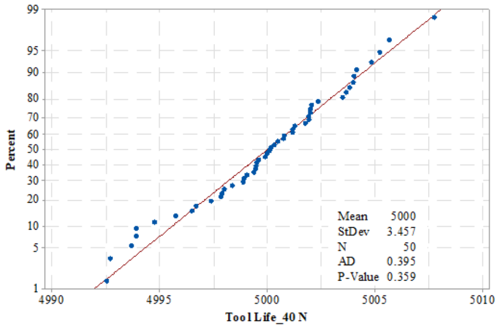
(f) Probability plot of tool life 10 N.



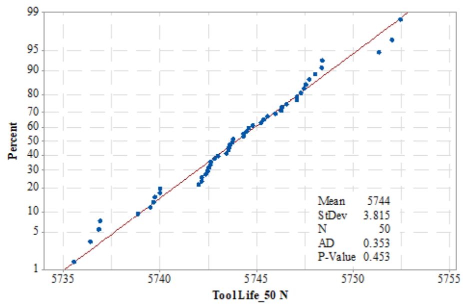
(g) Probability plot of tool life 20 N.



(h) Probability plot of tool life 30 N.



(i) Probability plot of tool life 40 N.



(j) Probability plot of tool life 50 N.

Fig. 4. The data investigation of principle's normal distribution.

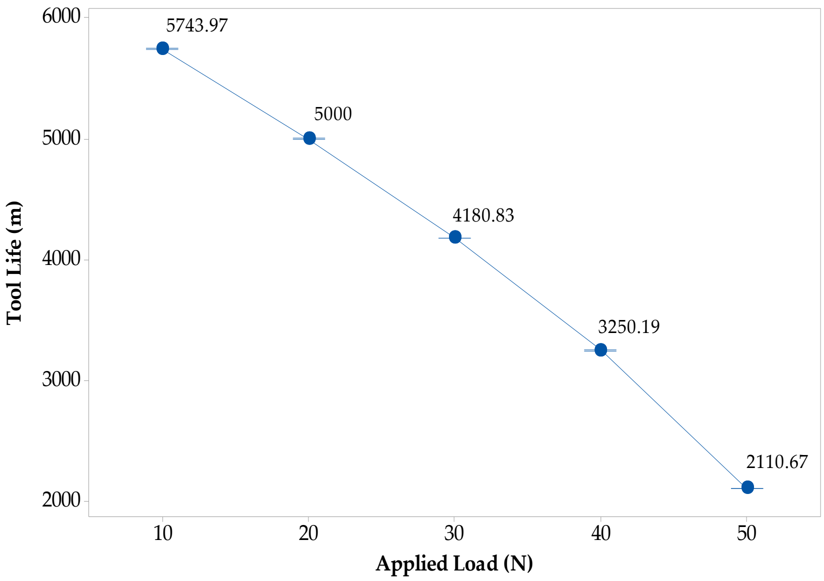


Fig. 5. The Monte Carlo simulation for the life models of WC-12Co.

4. Conclusion

In this study, the Taylor's equation in conjunction with Monte Carlo simulation was generated to the tool life model for prediction of WC-12Co coated SUS 400 stainless steel under sliding wear testing. Based on the tool life relationship of WC-12Co coated SUS 400 stainless steel between the applied loads with the sliding distance namely; the applied load was increased then the sliding distance reduced.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

S. Thermsuk : Responsible for designing research, planning research data, conducting experiments, analyzing results, writing, reviewing, compiling presentation content and summarizing research results.

P. Surin : Find relevant research information, prepare equipment and programs for testing.

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