

Tool Life Modeling for Drilling NAB Alloy Reinforced by SiC and Graphite

Dr. Haydar A.H. Al-Ethari, Hussain Hamza

IRQ- Babylon University/ College of Material's Engineering /Dept. of Engineering Metallurgy

Abstract:- A base Nickel-Aluminum Bronze (NAB) alloy of (Cu-9%Al-5%Ni-4%Fe) composition was prepared by compacting mixed powders of the constituents under a pressure of 656MPa and sintering in special atmosphere, then heat treated by quenching in water and then ageing. Various percentage of SiC with and without graphite were used to reinforce the alloy. The effects of these additives had been studied. A maximum width of flank wear of 450 μ m was considered as a criterion of tool life. Three cutting speed (0.95, 1.7, 3m/min) each with three feed rate (0.1, 0.25, and 0.4mm/rev) were considered as machining conditions using a 3mm-diameter high speed steel twist drill. The study showed that 2%SiC causes an increase of 13% in the porosity of the prepared composite and of 14.6% in its hardness. This causes a maximum reduction of 23% in tool life, but an addition of both SiC and graphite recorded a maximum reduction of 5.7% with an increase of 12% in hardness. The paper presents predictive mathematical models of tool life in relation with the various influencing parameters: machining conditions, porosity, hardness, and composition of the prepared samples, where different percentages of SiC and graphite were added to the base alloy.

Key words: flank wear, Graphite, modeling, NAB- alloy, PM, SiC, Tool life.

NOMENCLATURE

T- Tool life (Sec.); S- Percentage of added SiC; C- Percentage of added graphite; H- Hardness (HRB); P- Porosity (%); f- Feed rate (mm/rev.); V- Cutting speed (m/min.)

I. INTRODUCTION

Nickel-Aluminum Bronze (NAB) alloys have properties which make them the only choice for many engineering applications. Aluminum is the basic alloying element in this group of Cu-alloys giving it the high strength and excellent wear resistance, while Fe & Ni have very important effects on this alloy-system, so as Fe increases the alloy strength and Ni increases its corrosion resistance and yield stress. Many papers related to NAB alloy were published. They were focused on the effect of Al-percentage in the alloy, the effect of some other alloying element and cooling rates, the corrosion behavior of the alloy or on its wear behavior [1, 2, 3, 4]. Characteristics of PM technique with the specifications of NAB -alloy make it provide many engineering applications, but components with complex configuration (as cross holes, undercut, threads, blind holes,...etc) cannot be produced completely by this technique, so there is a need for machining operation. Drilling of short holes represents 30%

of the machining operations for the sintered products [5], so drilling processes will be considered in this study. Alloys as (C63200) prepared by PM suffer a weakness in their machining properties regarding their effect on tool life due to their specifications and their porosity. The porosity of conventional powder metallurgy parts is regarded as the dominant factor, which highly affecting on the cutting tool life. The detrimental effect of porosity leads to a constantly interrupted cut or intermittent loading-unloading which results in (mechanical and thermal) fatigue and produces undesirable vibrations and small impacts which accelerate the tool wear. The present work aims at the improvement of the tool life used in drilling NAB-alloy. Optimal results can be generated through combinational control of various influencing parameters. The present paper, therefore, emphasizes features of the development of comprehensive mathematical models for correlating the interactive and higher-order influences of the various machining parameters, such as the tools feed rate, the cutting speed, as well as the porosity, hardness, and composition of the prepared alloy samples, where different percentages of SiC and graphite were added to the alloy.

II. EXPERIMENTAL PART

Samples of a base NAB alloy with a chemical composition of (Cu-9% Al- 5% Ni - 4%Fe) according to ASTM was prepared by using PM technique. Other samples were prepared with different percentages of SiC and graphite. The prepared samples are coded as demonstrated in table (1). Powders with grain size of no more than 38 μ m were used. Wet mixing with acetone (2 wt %) for 6hrs in electric mixture was used. The samples were compacted at ambient temperature on an electric hydraulic press type (Soil test, Inc. - USA) using double action dies specially designed to prepare cylindrical samples with a diameter of 17mm and a height of 10mm. The samples were used for hardness, porosity, microstructure, and machining tests. A compacting pressure of 656MPa (with a loading rate of 1.7 ton/ min and a period of 1 min for the maximum pressure) was used for a maximum green density of the samples to be achieved. All samples were sintered in electric furnace type (SRJX 5.1, $\pm 5^{\circ}$ C accuracy, 1600 $^{\circ}$ C maximum temperature, China) in a special atmosphere at 950 $^{\circ}$ C for 45 min and cooled in still air. The sintered samples were heated to 900 $^{\circ}$ C for 50 min and quenched in water. A temperature of 500 $^{\circ}$ C for a period of 25 min was considered for aging treatment of the samples.

Porosity of the final (heat-treated) alloy samples was determined according to the following equation [6, 7]:

$$Porosity(Apparent)\% = \frac{W_w - W_d}{W_{sat} - W_s} \times 100$$

When: W_d – Dry weight of the samples; W_w - wet weight of the sample (the sample was weighted after immersing it for 24 hours in distilled water); W_{sat} – Saturated weight (the sample was weighted after immersing it for 5hrs. in pure water at 80°C); W_s – suspended weight (weighting the suspended sample in distilled water). A tool life of a high speed steel (HSS) 3mm diameter twist drill was measured. A maximum width of 450 μ m for the flank wear was regarded as a criterion for the tool life [8]. Dry blind drilling operations had been carried out on drilling machine type (AJAX, 56-1000rpm, 0.1-0.5mm/ rev, Great Britain). Three cutting speed (0.95, 1.7, and 3 m/ min) were used with three feed rate (0.1, 0.25, and 0.4 mm/ rev.). The width of the flank wear was measured every 60sec of drilling. Optical microscope type (1280XEQ-MM300TUSB) integrated with CCD camera was used to capture the image of worn tools and to measure the flank wear.

III. RESULTS AND DISCUSSION

A. Results of Physical and Mechanical Tests

The results, as demonstrated in table (1), show noticeable increase in hardness of the samples after treating them by quenching and aging. The recorded hardness number of the base alloy 82HRB is close to those recorded by other researcher [9]. SiC led to increase the hardness of the base alloy 94HRB as maximum due to its nature as a hard reinforcing phase, but it increases its porosity to 11.7%. Also adding graphite accompanied with SiC led to increase the hardness up to 92HRB as maximum and reduces its porosity to 9.72%. Figure (1) illustrates the structure of the only sintered alloy samples BA and A4. It seems that the major phase of these structure is the “ α ” phase, while no k-phases appeared as such phases can be resulted from slow cooling rate only [10]. SiC particles can be noticed clearly from Fig.(1).

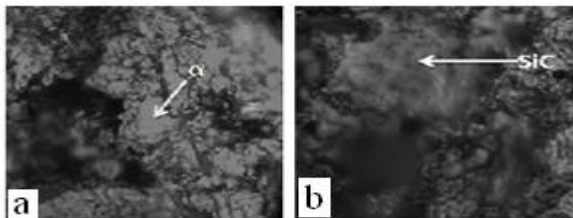


Fig.1. Microstructure of the sintered alloy samples(x800)
a) BA; b) A4.

Fig.(2) shows the resulted microstructure of the alloy samples BA, A2, and C2 after quenching in water. Marten site can be noticed as fine black lines (nodular martensite) created due to the change of β as a result of high cooling rate, and the white spaces in the microstructure shown represent α -phase.

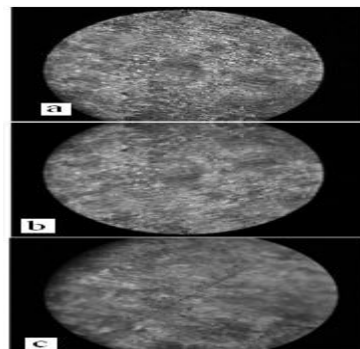


Fig.2. Microstructure of the final (heat treated) alloy samples(x800)
a) BA; b) A2; c) C2.

B. Results of Machining Tests

The tool life of the used drill according to the regarded machining conditions is demonstrated in table (1). The following can be concluded from the results:

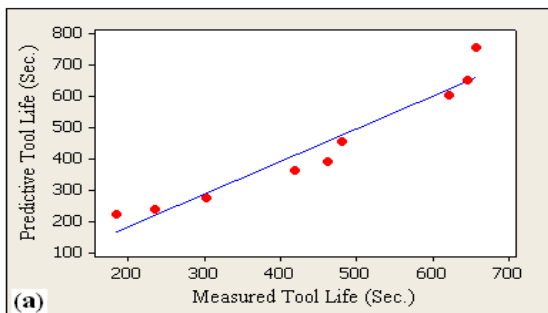
- For all alloy samples cutting speed or/ and feed rate have a negative effect on tool life. This is typical effects related to the fact that more heat is generated with higher cutting conditions so more wear at the flank surface of the tool. In addition an increase in feed rate causes a higher thrust force so a higher effect on the drill.
- Tool life is affected negatively with the percentage of SiC at all cutting conditions due to its abrasive effect and as it increases the hardness and porosity of the alloy samples.
- There is compensation between the negative effect of SiC on tool life and the positive effect due to the addition of graphite. This is clear with an addition of graphite together with 2% SiC especially at higher cutting speed and feed rate.

IV. MATHEMATICAL MODELS

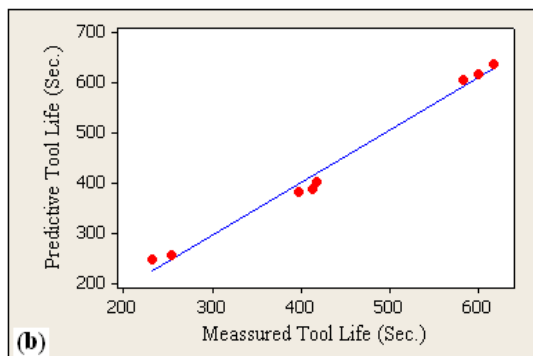
The tool life can be expressed as functions of : percentage of reinforcing element(s), hardness, porosity, cutting speed, and feed rate. These relations are expressed as shown in table (2). The constants of the ranked models were determined basing on a multiple regression method by using Minitab14 Software. Table (2) demonstrates also the values of the coefficient of the multiple regressions (R^2) for the designed models. Fig. (3) Shows the matching between the experimental values of the tool life and their predicted values due to the designed models. It indicates that the predicted values basing on the designed models are close match of their experimental values. The models, demonstrated in table (2), indicate the following:

- Hardness has a greater effect on tool life than porosity;
- cutting speed has a greater effect on tool life than feed rate;
- Graphite has positive effect on tool life, while SiC has a negative effect;
- There will be an improvement in tool life as well as in mechanical properties due to the addition of SiC and graphite.

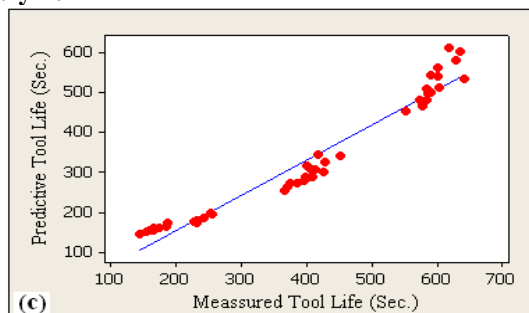
This is reflected by the values of all factors in model (10) in comparison with those of model (1).



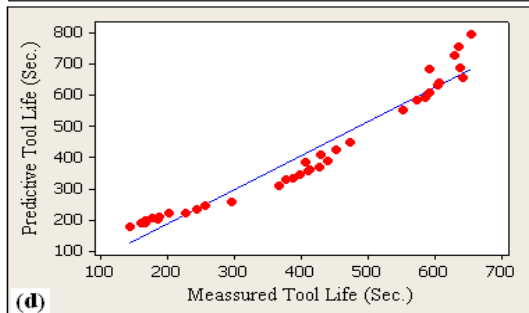
(a)



(b)



(c)



(d)

Fig (3): Scatter plot of the experimental and empirical values of tool life (a) For rank model (1) (b) For rank model (10) (c) For rank model (9) (d) for rank model (2)

Table (1): Results of tests for the prepared samples

Sample Code	SiC%	Graphite%	Final HRB	Porosity (%)	Speed (m/min)	Feed (mm/rev)	Tool Life (Sec)
BA	-----	-----	82	10.31	0.95	0.1	656
	-----	-----	82	10.31	0.95	0.25	646
	-----	-----	82	10.31	0.95	0.4	621
	-----	-----	82	10.31	1.7	0.1	480
	-----	-----	82	10.31	1.7	0.25	462
	-----	-----	82	10.31	1.7	0.4	418
	-----	-----	82	10.31	3	0.1	302
	-----	-----	82	10.31	3	0.25	234
A ₁	0.5	-----	86	10.62	0.95	0.1	653
	0.5	-----	86	10.62	0.95	0.25	637
	0.5	-----	86	10.62	0.95	0.4	605
	0.5	-----	86	10.62	1.7	0.1	473
	0.5	-----	86	10.62	1.7	0.25	438
	0.5	-----	86	10.62	1.7	0.4	412
	0.5	-----	86	10.62	3	0.1	294
	0.5	-----	86	10.62	3	0.25	201
A ₂	1.0	-----	89	10.82	0.95	0.1	636
	1.0	-----	89	10.82	0.95	0.25	642
	1.0	-----	89	10.82	0.95	0.4	591
	1.0	-----	89	10.82	1.7	0.1	452
	1.0	-----	89	10.82	1.7	0.25	426
	1.0	-----	89	10.82	1.7	0.4	397
	1.0	-----	89	10.82	3	0.1	254
	1.0	-----	89	10.82	3	0.25	186
A ₃	1.5	-----	91	11.21	0.95	0.1	628
	1.5	-----	91	11.21	0.95	0.25	603
	1.5	-----	91	11.21	0.95	0.4	573
	1.5	-----	91	11.21	1.7	0.1	428

	1.5	-----	91	11.21	1.7	0.25	409
	1.5	-----	91	11.21	1.7	0.4	375
	1.5	-----	91	11.21	3	0.1	242
	1.5	-----	91	11.21	3	0.25	184
	1.5	-----	91	11.21	3	0.4	159
A ₄	2.0	-----	94	11.64	0.95	0.1	591
	2.0	-----	94	11.64	0.95	0.25	584
	2.0	-----	94	11.64	0.95	0.4	551
	2.0	-----	94	11.64	1.7	0.1	406
	2.0	-----	94	11.64	1.7	0.25	386
	2.0	-----	94	11.64	1.7	0.4	365
	2.0	-----	94	11.64	3	0.1	226
	2.0	-----	94	11.64	3	0.25	165
C ₁	2.0	0.1	92	10.20	0.95	0.1	601
	2.0	0.1	92	10.20	0.95	0.25	587
	2.0	0.1	92	10.20	0.95	0.4	578
	2.0	0.1	92	10.20	1.7	0.1	400
	2.0	0.1	92	10.20	1.7	0.25	395
	2.0	0.1	92	10.20	1.7	0.4	371
	2.0	0.1	92	10.20	3	0.1	232
	2.0	0.1	92	10.20	3	0.25	173
	2.0	0.1	92	10.20	3	0.4	154
C ₂	2.0	0.3	89.5	9.72	0.95	0.1	618
	2.0	0.3	89.5	9.72	0.95	0.25	601
	2.0	0.3	89.5	9.72	0.95	0.4	583
	2.0	0.3	89.5	9.72	1.7	0.1	417
	2.0	0.3	89.5	9.72	1.7	0.25	413
	2.0	0.3	89.5	9.72	1.7	0.4	397
	2.0	0.3	89.5	9.72	3	0.1	253
	2.0	0.3	89.5	9.72	3	0.25	231
	2.0	0.3	89.5	9.72	3	0.4	185

Table 2: Tool life empirical models

Samples	Rank	Tool Life Model	R ² (%)
BA	(1)	$T = 506.571 * V^{-0.871} * f^{0.158}$	93.4
(A1-A4)	(2)	$T = 3.09 * 10^6 * S^{0.0258} * H^{-1.797} * P^{0.281} * V^{-0.985} * f^{-0.1567}$	94.3
	(3)	$T = 489.77 * S^{-0.102} * V^{-0.985} * f^{0.1567}$	94.2
(A2-A4) + (C1-C2)	(4)	$T = 19.95 * 10^6 * S^{-0.05} * C^{0.016} * H^{-3.1} * P^{1.4} * V^{-0.98} * f^{0.134}$	94.6
	(5)	$T = 549.51 * S^{-0.148} * C^{0.00695} * V^{-0.98} * f^{-0.134}$	94.3
2%SiC + (C1-C2)	(6)	$T = 558.2 * V^{-0.79} * f^{0.0374}$	98.6

V. CONCLUSION

- 1- Graphite reduces the porosity, while SiC increases it.
- 2- Adding graphite and SiC together causes a decrease in porosity and a slight increase in hardness.
- 3- Reinforcing by 2%SiC causes an increase of 13% in the porosity of the prepared composite and of 14.6% in its hardness. This causes a maximum reduction of 23% in tool life, but an addition of both SiC and graphite recorded a maximum reduction of 5.7% in tool life with an increase of 12% in hardness.

4- Reliable models for tool life have been developed, which takes into account the effect of graphite, SiC, hardness, porosity, and machining conditions. These models have been utilized to enhance the efficiency of machining the NAB-alloy hybrid composite. They can be used for optimization of a very important machining parameter (tool life) and development of expert system.

REFERENCES

- [1] Hiroyasa Mitani, Masaru Yokota, 1973, sintering in Mixed Powder Compacts of Multicomponent System for Aluminum-Bronze. J. Japan Soc. of powder and powder metallurgy.
- [2] Gorecki T., Korl S., Tokarski M., 1988, Effect of The Rate of Continuous Cooling From The Beta Phase Region On The Composition Structure And Properties of Cu-10Al-3Fe-2Mg. Novoch. Politech. Inst., Novocherkask, Russia.
- [3] Chen Rui-ping, Liang Ze-qin, 2007, Effect of Heat Treatment on Microstructure and Properties of Hot-Extruded Nickel-Aluminum-Bronze, Trans. Nonferrous met. Soc. China 17, p(1254-1258).
- [4] Lenard D. R., Bayley C. J. and Noren B. A., 2009, Detection of Selective Phase Corrosion of Nickel Aluminum Bronze In Seawater by Electrochemical Frequency Modulation, DOD corrosion conference, Canada.
- [5] Šalák A., Selecká M. and Danninger H., 2005, Machinability of Powder Metallurgy Steels, Cambridge International Science Publishing.
- [6] Abdul –Raheem Kadhim Abid-Ali, 2007, Investigation of Certain Shape Memory Alloys in Space Systems, Doctoral thesis, Babylon University.
- [7] ASTM International designation, 2003: B 328 – 96, Density, Oil Content, and Interconnected Porosity of Sintered Metal Structural Parts and Oil-Impregnated Bearings, ASTM International, United States.
- [8] Alden Kendall L., 2005, Tool Wear and Tool Life, ASM handbook, Vol-16, ASM International.
- [9] Dursun Özyürek, Tansel Tunçay, Cihan Degrmenç, 2009, Wear Behavior Of Nickel-Aluminum Bronzes Produced With Mechanical Alloying, Uluslararası _leri Teknolojiler Sempozyumu (IATS'09). Karabuk, Turkiye.
- [10] Calvin v. Hyatt, 1997, Review of Literature Related to Microstructure Development during Laser Surface Engineering of Nickel Aluminum Bronze, Defense research establishment Atlantic, Canada.

AUTHOR'S PROFILE

Hussain Hamza obtained his BSc. & his MSc in Materials Engineering from Babylon University-Iraq in 2012. He is interested in metallurgical engineering and metal cutting processes.



Prof. Dr. Haydar A.H. Alethari

Department of Materials Engineering,
Babylon University,

Hilla-Najaf Road P.O. 4- Al-Hilla, Iraq

E-mail: dralethari@uobabylon.edu.iq

Dr.Eng.Alethari@uobabylon.edu.iq

Haydar A.H. Alethari obtained his BSc. in Mechanical Engineering from Mosul University-Iraq in 1981. Then, he obtained his MSc and PhD degrees from Kharkov University (USSR-Ukraine) in 1988 and 1991, respectively. He is interested and a researcher in manufacturing, traditional and advanced cutting processes of composites and metals. Currently, he is a team leader of MSc. students in Materials Engineering, Babylon University, Iraq to develop mechanical and physical characteristics of advanced materials.