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Micro-Grooving of Aluminum, Titanium and Magnesium Alloys by Acidithiobacillus Ferrooxidans Bacteria

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ABSTRACT. Micro-grooving technology through using renewable natural sources has been presented in this work. Applying bacteria is known for many years as the main removal tool of metal, such as copper and tin as well as plastics; so called 'Biomachining'. Micro-grooving is critically important for the fields of electronics and medicine. Within this work, biological micro-grooving by Acidithiobacillus Ferrooxidans bacterium (A.F), as an innovative method for different metals, has been used in precise industries such as aerospace and electronic, including pure magnesium, magnesium alloy E21, titanium alloy Vt20 and aluminum alloy. Comparing the recognized advantages and disadvantages of the proposed method for each metal showed that A.F bacteria in the medium causes metal surface removal and very fine surface grooves through applying special tools. However, the tool may lack any surface collision and create the solution including bacteria in desired size and shape at the surface. It is also demonstrated that removal in titanium and aluminum alloys is pretty low due to oxide coating. It is also possible to groove pure magnesium and magnesium alloy surface by width of 0.05 mm.

Keywords: Micro-grooving; Biomachine; Aluminum alloy; Titanium alloy; Magnesium alloy; Acidithiobacillus Ferrooxidans.

INTRODUCTION

By growing new materials used in industry, the need to expand new machine-building methods has been also increased.[1] An innovative process of metal removal is called 'Biomachining', which is done using acid bacteria (Acidithiobacillus) successfully employed for several metals.[2] Among analyzing methods of technical processes, experimental analysis is more important than other ones revealing that Biomachining is possible and the groove depth linearly could be increased by the machining time.[3, 4] Contrary to common processes, in which concentrating chemical and/or thermal energy on the machining point probably causing a damaged layer or destroying metallurgical properties, such problems are not considered in Biomachining.[5] Some chemolithotrophic bacteria are used for energy obtaining from minerals and removing air carbon dioxide, among which Acidithiobacillus Ferrooxidans (A.F) is one of the bacteria corrode the metals.[6] These bacteria use the produced energy by iron or sulfur oxidation for purification of carbon dioxide of air.[7] This is a type of short bacillus bacterium (rod-like) with about 0.5 micrometers in diameter and 1 micron in length. Because of the small removal volume, it is particularly useful as a micro machining tool.[8]

Micro-grooving is critically important in electronics and medicine. Electronic instrumentation and micro-electronic and mechanic systems (MEMS) utilize highly precise grooving on hard metals.[9, 10] Precise grooving is particularly used for bone implants where it requires tiny and precise grooves.[11] Current existing

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methods of micro-grooving are problematic, costly and time-consuming due to thermal and chemical placements.[12, 13] Aluminum is also largely used in medicine, electronics and nano industry because of its heat and electricity conduction as well as light weight for automotive industry, aviation systems, astronomical telescopes and electronics.[14] Titanium has been largely applied in medicine, electronics, and nano industries for dental implants, orthopedic, and aerospace products because its high corrosion resistance, good biocompatibility, inactiveness (low activity), and proper mechanical properties.[15] Pure magnesium and magnesium alloy are largely used for light weight, high machinability, and surface oxidation in medicine, electronics and nano-industries like using for automobile parts and aircraft products.[16] In this paper, A.F bacteria micro-grooving in aluminum and titanium alloys, pure magnesium and its alloy are investigated.

MATERIALS AND METHODS

The required medium for A.F bacterium is named 9k, which is provided by the described components in Table 1. First, solutions 1 and 2 are prepared and then they are mixed and Agar is added to the solution. The solution is poured into a plate with 10 cm diameter and the bacterial culture is implemented. After one week, bacteria solid culture in an incubator at 37˚C and the bacterium is colonized in the medium. Liquid medium was also used in order to have machining and grooving in desired size (pretty tiny grooves) more precisely and more controllable. In this regard, 20 ml culture medium of the first and second solutions was poured into a 25 ml tube; then, 600 ml A.F bacteria is added. The tube was placed into an incubator at 30˚C. The tube was removed from the incubator after one week clearly showing bacteria growth as seen in Fig. 1.

Table 1: Solution components of solid media.

Solution 1	Solution 2	Solution 3
10 g $FeSO_4$	0.9 g $(NH_4)_2SO_4$	1 g /100 mL
pH = 0.5	0.35 g $MgSO_4$	Bacterial Agar
500 mL H_2O	0.175 g Tryptone Soy Broth	
	500 mL H_2O	

Table 2: Chemical composition (%) for Vt20 titanium.

Fe	C	Si	Mo	V	N	Ti	Al	Zr
0.25	0.1	0.15	0.5-2	0.8-2.5	0.05	85.15-91.4	5.5-7	1.5-2.5

Table 3: Chemical composition (%) for aluminum 7075.

Al	Fe	Cr	Cu	Si	Zn	Mg	Mn	Ti
87.1-91.4	0.5	0.18-0.28	1.2-2	0.4	5.1-6.1	2.1-2.9	0.3	0.2
Other, each		**Other, total**						
0.05		0.15						

Table 4: Chemical composition (%) for magnesium E21.

Gd	Nd	Zr	Zn	Mn	Fe	Ag	TRE
1.2	2.7	0.49	0.4	0.001	0.003	0.01	4.2
Mg: Balance							

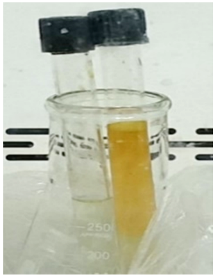


Fig. 1: One week bacteria growth in the medium in an incubator at 30˚C.

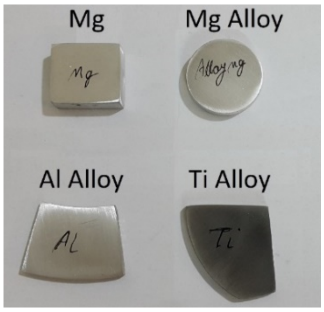


Fig. 2: Metal samples.

Fig. 3: Plate containing four metal sample metal and distilled water.

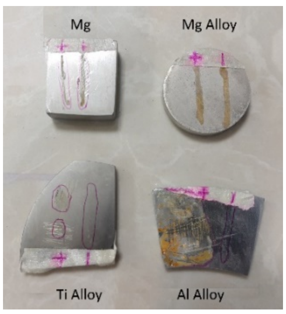
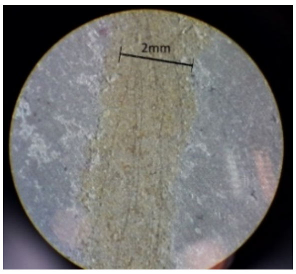


Fig. 4: Samples after 24 h of incubation ('+' shows the bacteria and '-' merely shows the medium).

As represented in Fig. 2, four different kinds of metals are used as research samples including aluminum alloy 7075, titanium alloy Vt20, magnesium alloy E21 and pure magnesium. Next, sample surfaces are desirably smeared by the solution of bacterial medium and non-bacterial medium in narrow groove through means of loop. The value of smeared solution on the surface is measured by precise instrumentation in order to have the given groove to be very tiny. Chemical properties of aluminum alloy 7075, titanium alloy Vt20, magnesium alloy E21 and pure magnesium are illustrated in Tables 2- 4. The sample metals are initially rinsed by alcohol at 70˚C; then, they are autoclaved at 120 ˚C for 20 min. Following smearing of the bacterial and non-bacterial medium on the surface, all four metals are placed into a plate (10 cm diameter) with some distilled water (to keep the medium moist) and capped (Fig. 3). Then, the plate is put into the incubator at 30˚C for 24 h (Fig. 4) and the samples are tested after. The symbol '+' represents that the groove has been machined by the bacterial solution, and the symbol '-' represents that the groove has been machined by the non-bacterial solution. The grooves in the opposite direction of the bacterial groove are due to comparing the groove by mechanical instruments with bacterial groove.

a)



b)

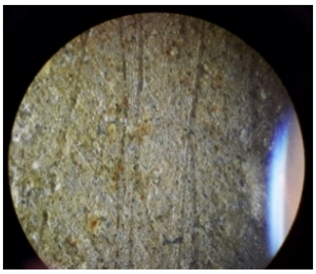


Fig. 5: Microscopic view of a) magnesium alloy and b) pure magnesium sample.

RESULTS AND DISCUSSION

Fig. 5 illustrates microscopic view of bio removal by A.F bacteria from pure magnesium and magnesium alloy. As clearly observed, the orange lane is for bacterial medium spread out following surface smear. The tiny grooves, along the orange lane, are microgrooves created by bacteria; whereas, non-bacterial medium shows none of such grooves. Therefore, it may be stated that acidic context shows no grooving effect on the metal surface in the proposed method; while, in bacterial medium, the bacteria for surviving and nutrition, cause metal removal and grooving.

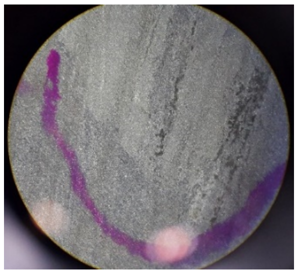


Fig. 6: Microscopic view of A.F bacteria effect on titanium alloy Vt20.

The yellow lane is about 2 mm; hence, the width and depth of the grove is almost 0.05 mm. To assure the grooving occurred, mechanical grooves were slotted in opposite direction (right to left) with a vertical force of 10 N (as seen in Fig. 5); however, it only made tiny, small scratches not comparable to bacterial grooving.
Fig. 6 represents the microscopic view of A.F bacteria effect on titanium alloy Vt20. In a purple highlighted area, there is seen a low and high (bold) contrast range. The lighter area is where the bacteria influenced. There is no sign of bacterial corrosion; rather, it only created a layer that may not be removed by alcohol rinsing or even mechanical scratching. It is probably oxidized.
The effect of bacteria on aluminum is not microscopically visible such that it even shows no effect of color contrast on surface.

CONCLUSION

The smearing method of liquid medium on surface is a new method, which has been firstly used in this paper with success. This paper tested micro-grooving on the surface of aluminum alloy 7075, Vt20 titanium alloy, magnesium alloy E21 and pure magnesium. The proposed method properly removed pure magnesium and magnesium alloy surface and grooved a 0.05 mm slot. Furthermore, the method also revealed that removal and consequently grooving is impossible through aluminum and titanium alloys. Micro-grooving method, in this paper, may be applied in electronics and medicine as it lacks chemical and thermal disadvantages. On the other hand, since these grooves are produced by living microorganisms, the grooves may significantly contribute in accepting artificial implants (like magnesium alloy) to be employed inside the human body.

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