



International Journal of Intellectual Advancements and Research in Engineering Computations

Modification of copper surface for increasing contact angle of water droplet using physical methods

R.Yuvaraj¹, K. S. Sakthi Monish², R. Sanju Aravind², M. Sanjay², B. Santhosh²

¹Assistant Professor, ²UG Students

Department of Mechanical Engineering, Sona College of Technology, Salem-5, Tamil Nadu, India

ABSTRACT

In the present work the morphology of copper surface is modified to increase the contact angle of water droplet using by physical metal removal processes. Copper is used in many industrial applications like power plants, refrigerators, and industrial condensers etc. Modification of copper surface is performed using physical methods to increase the contact angle using CNC lathe, conventional lathe, Electrical Discharge Machine (EDM). Eight different samples are taken by varying the parameters like depth of cut (0.1-0.6 mm), feed rate (0.1-0.003 mm/rev), speed (637-1274 rpm) to obtain increase in contact angle of water droplet (31.7° - 64.28°) on the prepared surface. The maximum contact angle of 64.28° is obtained from the sample-7 with depth of cut (0.6 mm), feed rate (0.001 mm/rev) and speed (637 rpm). The prepared surface is characterized by microscopic image for surface morphology. The modified copper surface is validated with the bare copper surface which gives 40.15% increase in contact angle. Also, modifications of the mild steel and copper surfaces are carried in conventional lathe and EDM respectively. This approach requires no complex processing equipment's or time-consuming preparation and no toxic reagents are involved. The process involved in modification of copper surface is an eco-friendly attempt and inexpensive compared with all other chemical methods.

Keywords: Contact angle, Copper surface, Lathe, CNC lathe, Electrical discharge machine.

INTRODUCTION

Modifying surfaces can be achieved in many different ways. As the water droplet falls on to the surface, it spreads out like a traditional drop on any other surface. But, unlike typical surfaces, the structure causes it to come back together again until it lifts off the surface completely. The wet ability of solid surfaces is an important property and depends on surface roughness. In recent years, surfaces with increased contact angle property have been successfully explored on metallic surfaces by a variety of methods such as chemical etching [1], electro deposition [2]. Water contact angle (CA), have attracted increasing attention due to their potential industrial applications in self-cleaning, corrosion resistance, fluid drag reduction

and oil/water separation and so on [4].For the past decades, numerous researches have been conducted to control the wetting property of a solid surface to make it hydrophobic and some of them were interested. Inexpensive and eco-friendly approaches are an increasing demand for industrial applications and mass production of high contact angle surfaces [3].

This surface also used for many other applications including, bio-medical devices, such as the interior of tubes and syringes that deliver fluids to patients, hulls of ships, the exterior of torpedoes or submarines and airplane wings that will resist wingtip icing in cold or humid conditions. Even more interesting application is the role this technology can play in producing

Author for correspondence:

Department of Mechanical Engineering, Sona College of Technology, Salem-5, Tamil Nadu, India

cleaner and more efficient energy. Nearly every power plant across the country creates energy by burning coal or natural gas to create steam that expands and rotates a turbine. Once that has happened, the steam needs to be condensed back into a liquid state to be cycled back through, explained the researchers. If power plant condensers can be built with optimal superhydrophobic surfaces that process can speed up in significant ways, saving time and lowering costs to generate power. If you have these surfaces, the fluid isn't attracted to the condenser wall, and as soon as the steam starts condensing to a liquid, it just rolls right off. And so, you can very, very quickly and efficiently condense a lot of gas. Liu et al. [6] fabricated a superhydrophobic aluminum alloy surface with good corrosion resistance by anodic oxidation and a self-assembly process. Xu et al. [7] reported superhydrophobic thin films fabricated on chemically cleaned aluminum alloy substrates by electro deposition process in the ethanolic solution containing Ni^{+2} ions and stearic acid under applied DC voltage. Karthik et al. [8] presented an approach to fabricate a corrosion-resistant super hydrophobic composite coating on the aluminum surface from the hybrid assembly of inorganic-organic layers via electroless copper deposition followed by surface modification with a lauryl amine.

These methods are still subjected to certain limitations like a complicated procedure, expensive materials and potential hazards to the environment caused by chemical reagents [9, 10, 11]. The frequent use of strong corrosive or toxic fluorine containing reagents will endanger the environment [12, 13]. Shiet al. [14] successfully prepared superhydrophobic coatings on aluminum substrates through acid etching followed by modifications with Nano-silica and fluorosilane. Tests showed superhydrophobic coatings increased the corrosion potential of aluminum substrates but in here our paper focuses on to get the surface by physical methods.

The present paper focuses on increasing the contact angle on the surfaces by physical methods. The methods that we focused on the machining the surface is conventional lathe machining, CNC machining, electrical discharge machining. While machining on the copper surface and mild steel, we get the concentric grooves on the surface. The increase in contact angle on the surface will decrease the contact area between the droplet and the surface, thus it will increase the area of the vapour medium and the surface. So it will increase the heat transfer rate in condensation. Eight different samples are taken by varying the parameters like depth of cut (0.1-0.6 mm), feed rate (0.1-0.003 mm/rev), speed (637-1274 rpm) to obtain increase in contact angle of water droplet (31.7° - 64.28°) on the prepared surface. The maximum contact angle of 64.28° is obtained from the sample-7 with depth of cut (0.6 mm), feed rate (0.001 mm/rev) and speed (637 rpm). The prepared surface is characterized by microscopic image for surface morphology. The modified copper surface is validated with the bare copper surface which gives 40.15% increase in contact angle. By these high processing efficiencies can be guaranteed, therefore it provides a new strategy for a cost-effective and non-toxic method to prepare increase in contact angle, which will offer potential opportunities for a large area of production and industrial application of contact angle without complex processing equipment or time-consuming preparation.

CONTACT ANGLE

One of the methods to quantify the wetting behavior of a surface is to measure its contact angle (CA). The Contact angle is the angle formed by the liquid and the three-phase boundaries. The contact angle provides information on the interaction energy between the surface and the liquid.

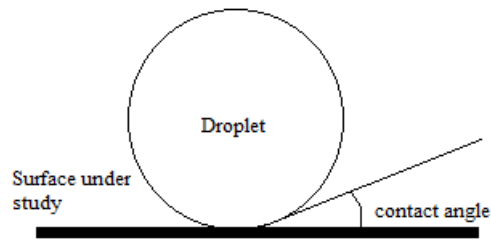


Fig. 1 A drop on a rough surface and the contact angle (θ)

If the value is towards 30 it is defined as hydrophilic, if it is towards 90 it is defined as hydrophobic. On most hydrophobic surfaces, water droplets will exhibit a contact angle between 00 and 300. if the droplet is placed on less strongly hydrophilic solids, such as a piece of metal, it will have a contact angle up to 900 or larger depending on the material. Highly hydrophobic surfaces have the water contact angles as high as 1500 or even nearly 1800. These surfaces are called superhydrophobic.

On these surfaces, water droplets simply rest on the surfaces, without actually wetting to any significant extent. Surface with nanostructures tends to have a very high contact angle, which can reach the increased contact angle on surface level. This can be understood by imagining that a surface

with Nano-roughness is formed of a series of very small pillars. When a droplet rests on this “mat of pillars” it is a contact with a large fraction of air. If we think of the ideal case of a single droplet of water in the air. It will have a totally spherical shape. For a droplet of water on a surface with a large air fraction, the larger this fraction, the closer we got this “ideal” situation.

WETTING MODELS

Based on the liquid droplet on the surface of solid three different models are available, we have three different wetting models young’s model, wenzel model, cassie and baxter model. The difference between these model properties are given below,

Young’s model

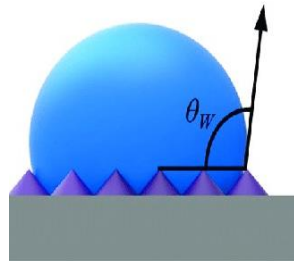


Fig. 2 An example of Young's model

On roughened surfaces, there are mainly two different equilibrium states: Wenzel and Cassiestate. When a liquid can fully wet the surface texture, the thermodynamic equilibrium contact angles of a liquid droplet is describing the Wenzel model.

Droplets in this fully wetted Wenzel state typically display very high hysteresis because the contact line of the droplets becomes severely pinned on surface asperities.

Wenzel model

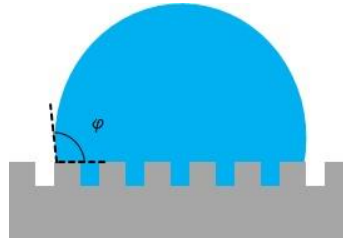


Fig 3: Example of the Wenzel model

On roughened surfaces, there are mainly two different equilibrium states: Wenzel and Cassie state. when a liquid can fully wet the surface texture, the thermodynamic equilibrium contact angles of a liquid droplet is described by the

Wenzel model droplets in this fully wetted Wenzel state typically display very high hysteresis because the contact line of the droplets becomes severely pinned on surface asperities.

Cassie and Baxter model

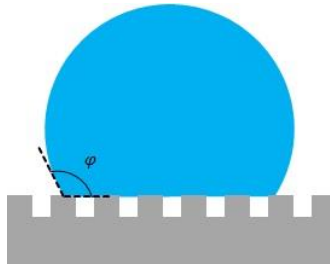


Fig. 4 cassie & baxter wetting model

Cassie and Baxter⁴ (CB) further considered that if the substrate is flat but consists of randomly distributed "n" different type of materials on the

surface and each of these materials are characterized by their own surface energies/tensions [5].

EXPERIMENTAL SETUP

Electrical discharge machine



Fig 5 setup for electrical discharge machine

In Electrical discharge machining (EDM), also known as spark machining, spark eroding, burning, die sinking, wire burning or wire erosion, is a manufacturing process whereby a desired shape is obtained by using electrical discharges. The material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the

electrodes is called the tool-electrode, or simply the "tool" or "electrode," while the other is called the work piece-electrode, or "work piece." The process depends upon the tool and work piece not making actual contact. By Electrical discharge machining takes 5hrs 30min to cut the copper work piece of diameter 75mm with molybdenum wire of its diameter 0.180mm

Center lathe



Fig. 6 Setup for center lathe

The lathe is one of the most versatile and widely used machine tools all over the world. It is commonly known as the mother of all another machine tool. The main function of a lathe is to remove metal from a job to give it the required shape and size. The job is securely and rigidly held in the chuck or in between centers on the lathe machine and then turn it against a single point cutting tool which will remove metal from the job in the form of chips. Machine equipment for cutting metal wherein a workpiece is held and rotated while a firmly-placed tool is applied in order to create a circular product.

Flat surfaces may be made by facing, screw cutting, boring and drilling procedures. The workpiece is typically held in a chuck or by two centers. Centre lathe was used for machining the mild steel surface. The variation in the parameter are depth of cut, feed rate and speed were maintained at constant in center lathe. The variation in the contact angle was tabulated for



Fig. 7 Setup for CNC machine

analyzing. The microscope images are captured for morphological studies.

CNC machine

CNC Machining is a process used in the manufacturing sector that involves the use of computers to control machine tools. Tools that can be controlled in this manner include lathes, mills, routers, and grinders. The CNC in CNC Machining stands for Computer Numerical Control. Under CNC Machining, machine tools function through numerical control. A computer program is customized for an object and the machines are programmed with CNC machining language (called G-code) that essentially controls all features like feed rate, coordination, location, and speeds. With CNC machining, the computer can control exact positioning and velocity. CNC machining is used in manufacturing both metal and plastic parts. From the Copper sample, the maximum contact angle was achieved in sample 7

which was shown in Fig 8.g. The contact angle difference from sample 1 to sample 7 was 33.18°. It was obtained by varying the feed rate and depth of cut while reducing the feed rate increases the contact angle by CNC lathe.

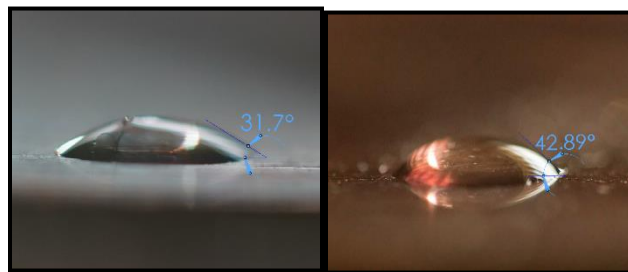
RESULTS AND DISCUSSION

CNC lathe machine

The variation in the contact angle was obtained by varying the CNC lathe parameters like feed rate, depth of cut. The variation in contact angle was tabulated for the analyzing. The Analyzing process carried out by measurement of contact angle, Morphological study by microscope, graph is plotted.

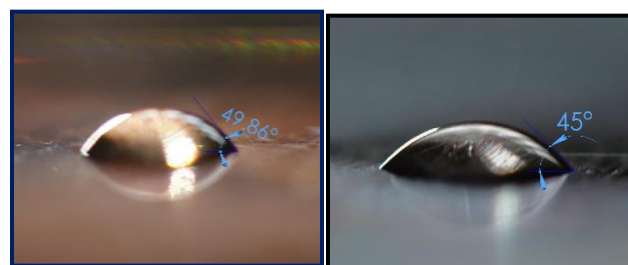
Table .2 Results of CNC machining on copper

<i>Sample</i>	<i>Depth of cut</i>	<i>Rpm</i>	<i>Feed</i>	<i>Cutting speed</i>	<i>Contact Angle</i>
1	0.1	1274	0.2	300	31.7°
2	0.2	1062	0.15	250	42.89°
3	0.2	637	0.02	150	49.86°
4	0.2	637	0.2	150	45°
5	0.4	849	0.1	200	43.57°
6	0.6	637	0.05	150	56.44°
7	0.6	637	0.001	150	64.28°
8	0.6	637	0.003	150	60.51°



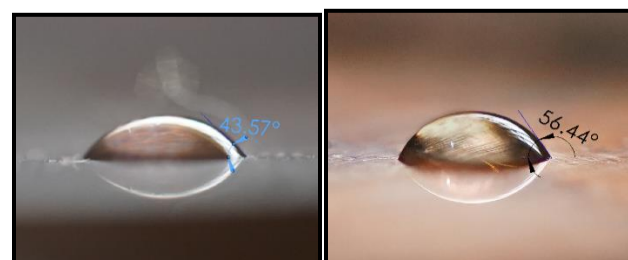
(a)

(b)



(c)

(d)



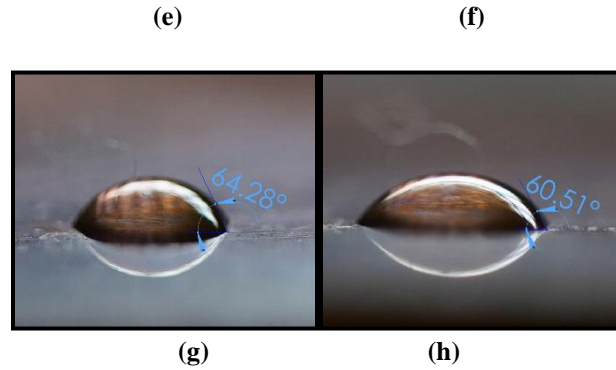


Fig. 8 Images of the modified surfaces with different contact angles of water droplet (a) Sample-1, (b) Sample-2, (c) Sample-3, (d) Sample-4, (e) Sample-5, (f) Sample-6, (g) Sample-7, (h) Sample-8

By Electrical discharge, machining takes 5hrs 30min to cut the copper workpiece of diameter 75mm with molybdenum wire of its diameter 0.180mm.

Eight different samples are taken by varying the parameters like depth of cut (0.1-0.6 mm), feed rate (0.1-0.003 mm/rev), speed (637-1274 rpm) to obtain increase in contact angle of water droplet (31.7° - 64.28°) on the prepared surface. The maximum contact angle of 64.28° is obtained from the sample-7 with depth of cut (0.6 mm), feed rate (0.001 mm/rev) and speed (637 rpm). The prepared surface is characterized by microscopic image for surface morphology. The modified copper surface is validated with the bare copper surface which gives 40.15% increase in contact angle.

Increasing the contact angle reduces the contact area between the water droplet and surface it increases the vapor medium in condenser tube it increases the heat transfer rate the convection

process take place in the water droplet and the plate surface; conduction process take place in the plate.

Comparing the contact angle with bare surface of the copper it shows the increase in contact angle. From the Copper sample, the maximum contact angle was achieved in sample 7 which was shown in Fig 8. (g). The contact angle difference from sample 1 to sample 7 was 33.18° . It was obtained by varying the feed rate and depth of cut while reducing the feed rate increases the contact angle.

Comparison of surfaces

Comparing all sample in the copper surface Fig 8 (a) sample1 shows the lowest contact angle which is of 31.7° . The contact angle was increasing while reducing the Feed rate. The sample 7 which as the highest contact angle of 64.28° . The contact angle was obtained by the physical method it was permanent and non-toxic. It improves the condensation process and it also used in a wide range of applications.

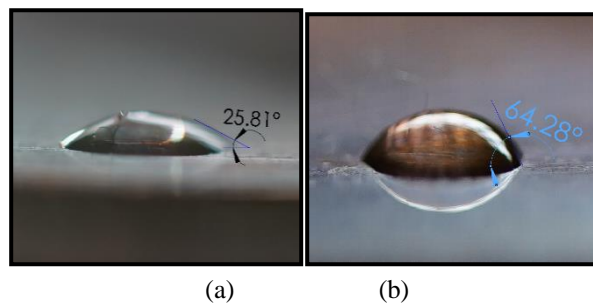


Fig. 9 Images of bare surface and modified surface (a)-bare surface, (b)-modified surface

By the Fig we got to know that the bare surface of the copper have a contact angle of 25.8° and the maximum contact angle that we got through physical method is 64.28° . The difference between the two surfaces is 38.4° . By this we gotta know that contact angle of the surface can be increased by modifying the surfaces of various samples. The contact angle is increased upto 40 percentage with

64.28° contact angle compared to bare surface of contact angle 25.8° .

Microscope images for Copper

The images are captured on the copper surface which is machined on the CNC by varying feed rate, depth of cut. The all images are captured on the 5x magnification range in microscope. The variation in the sample are analyzed.

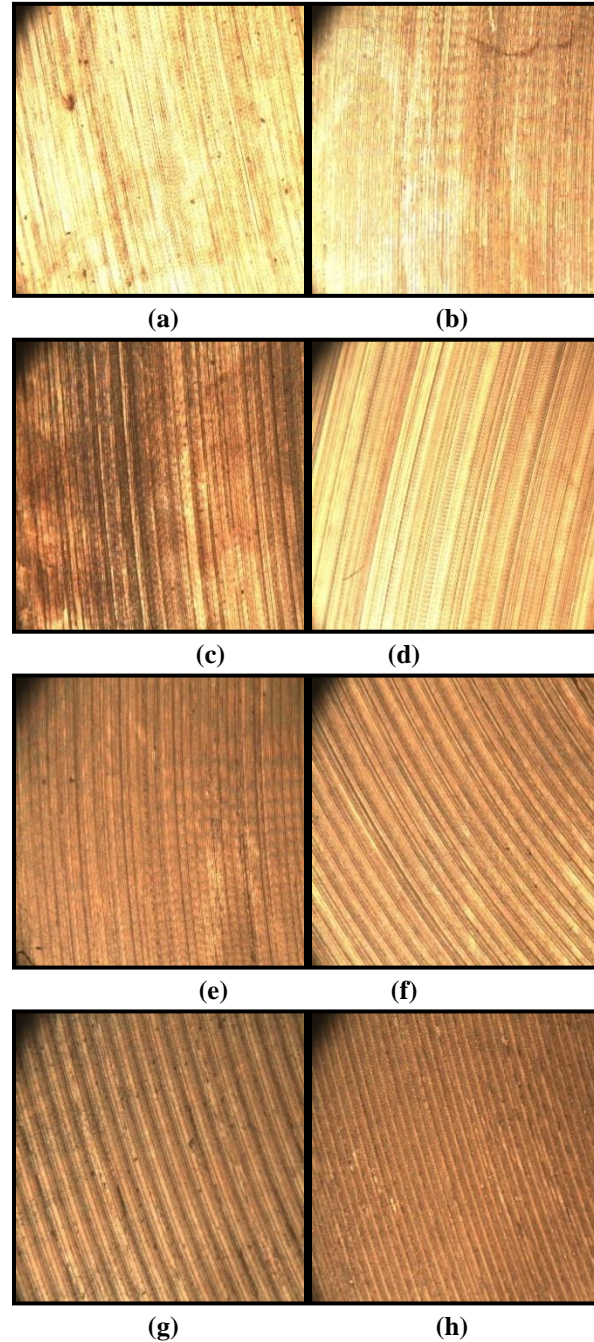


Fig. 10 Microscopic images taken 5X magnification with various feed

(a)Sample-1, (b) Sample-2, (c) Sample-3, (d) Sample-4,
(e)Sample-5, (f) Sample-6, (g) Sample-7, (h) Sample-8.

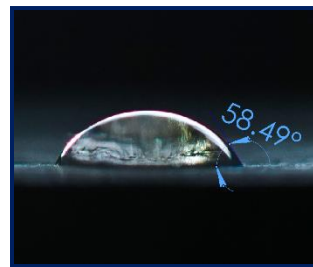
Centre lathe machine

Centre lathe was used for machining the mild steel surface. The variation in the parameter are depth of cut, feed rate and speed was maintained at

constant in centre lathe. The variation in the contact angle was tabulated for analyzing. The microscope images are captured for morphological studies.

Table 3: Results for lathe machining of mild steel

Sample	Depth of cut	Rpm	Feed	Contact Angle
1	0.06	150	0.04	61.64°
2	0.2	150	0.06	58.49°
3	0.5	150	1.6	31.95°



(a) (b)



(c)

Fig. 11 Images of the modified surfaces with different contact angles (a)Sample-1, (b)Sample-2, (c)Sample-3

Sample 1 has the contact angle 61.64° which is higher than Sample 2 and Sample 3. The contact angle difference between Sample 1 and Sample 3 was 29.69°. Comparing all sample in the Mild steel surface Fig 11 sample 1 shows the Highest contact

angle which is of 61.64°. The contact angle was increasing while reducing the Feed rate. Sample 3 which as the lowest contact angle of 31.95°. The contact angle was obtained by the physical method it was permanent and non-toxic.

Microscope images Mild steel

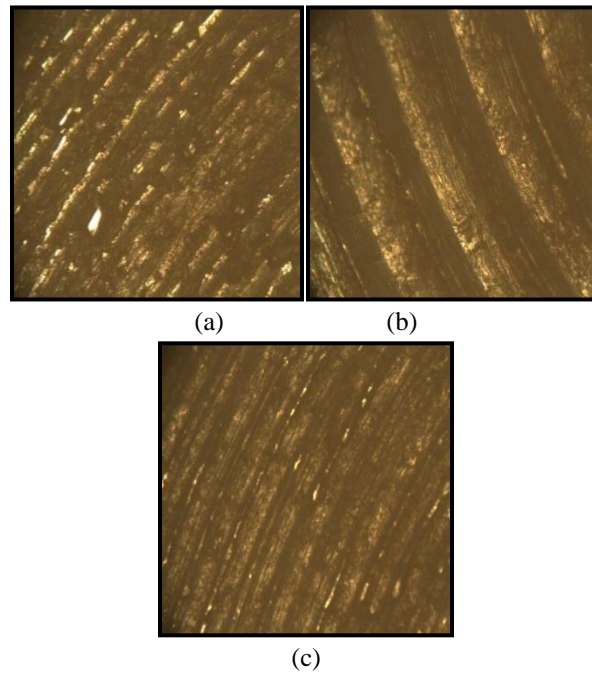
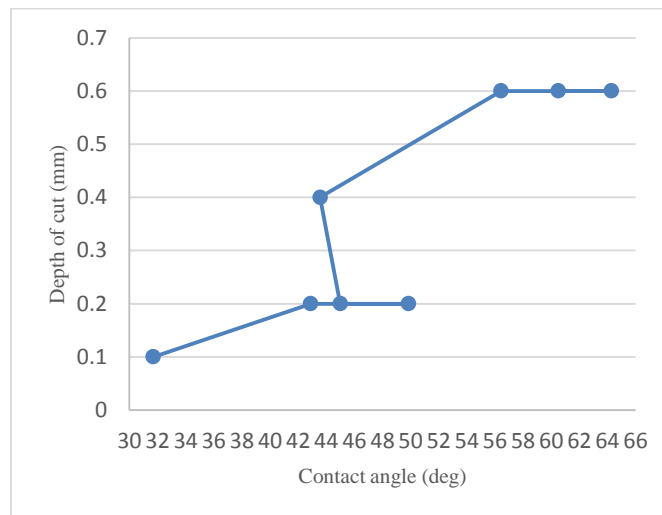


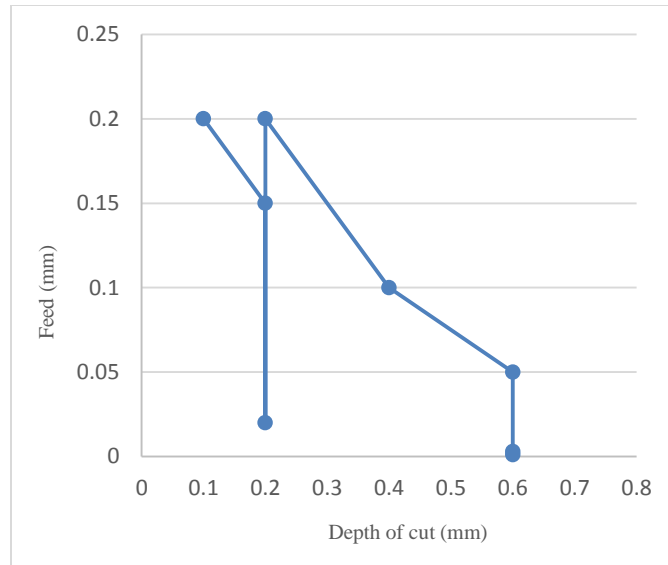
Fig. 12 Microscopic images taken 5X magnification with various feed (a)=0.04mm, (b)= 0.06mm, (c)=1.6mm

Numerical comparison



In the above graph we show the numerical comparison that has been plotted above has shown us a significant change in contact angle this is

possible only when the depth of cut is changed. The gradual increment in the depth of cut has given us a rise in contact angle.



In the above graph is plotted between the depth of cut and feed rate, in this one we can able to see that with the higher depth of cut and with lesser feed rate the maximum contact angle is obtained.

CONCLUSION

In conclusion, we present a modified surface of copper and compared with mild steel, the increased contact angle was achieved by machining in CNC and Centre Lathe. By these high processing

efficiencies can be guaranteed, therefore it provides a new strategy for a cost-effective and non-toxic method to prepare increase in contact angle, which will offer potential opportunities for a large area of production and industrial application of contact angle without complex processing equipment or time-consuming preparation. The method proposed in our work causes no harm to the environment as it does not require any fluorinated chemicals or strong acid and alkali reagents.

REFERENCES

- [1]. Y. Huang, D.K. Sarkar, X.G. Chen, Superhydrophobic aluminum alloy surfaces prepared by chemical etching process and their corrosion resistance properties, *App. Surf. Sci.* 356, 2015, 1012–1024
- [2]. J. Liang, D. Li, D. Wang, K. Liu, L. Chen, Preparation of stable superhydrophobic film on a stainless steel substrate by a combined approach using electrodeposition and fluorinated modification, *App. Surf. Sci.* 293, 2014, 265–270.
- [3]. C.Y. Jeong, C.H. Choi, Single-step direct fabrication of pillar-on-pore hybrid nanostructures in anodizing aluminum for superior superhydrophobic efficiency, *ACS Appl. Mater. Interfaces* 4, 2012, 842–848.
- [4]. Jiyuan Zhu, A novel fabrication of superhydrophobic surfaces on the aluminum substrate
- [5]. S. Banerjee, Simple derivation of Young, Wenzel, and Cassie-Baxter equations and its interpretations.
- [6]. C. Liu, F. Su, J. Liang, Facile fabrication of a robust and corrosion resistant superhydrophobic aluminum alloy surface by a novel method, *RSC Adv.* 4, 2014, 55556–55564
- [7]. N. Xu, D.K. Sarkar, X. Chen, W. Tong, Corrosion performance of superhydrophobic nickel stearate/nickel hydroxide thin films on aluminum alloy by a simple one-step electrodeposition process, *Surf. Coat. Technol.* 302, 2017, 173–184.
- [8]. N. Karthik, T.N.J.I. Edison, Y.R. Lee, M.G. Sethuraman, Fabrication of corrosion resistant mussel-yarn like superhydrophobic composite coating on the aluminum surface, *J. Taiwan Inst. Chem. E* 77, 2017, 302–310
- [9]. L. Feng, H. Zhang, Z. Wang, Y. Liu, Superhydrophobic aluminum alloy surface: fabrication, structure, and corrosion resistance, *Colloids Surf. A. Physicochem. Eng. Asp.* 441, 2014, 319–325

- [10]. S. Zheng, C. Li, Q. Fu, M. Li, W. Hu, Q. Wang, M. Du, X. Liu, Z. Chen, Fabrication of self-cleaning superhydrophobic surface on aluminum alloys with excellent corrosion resistance, *Surf. Coat. Technol.* 276, 2015, 341–348.
- [11]. C. Chen, S. Yang, L. Liu, H. Xie, H. Liu, L. Zhu, X. Xu, A green one-step fabrication of superhydrophobic metallic surfaces of aluminum and zinc, *J. Alloy. Comp.* 711, 2017, 506–513.
- [12]. D. Cui, W. Li, T. Li, H. Zhang, Development of a simple method for the fabrication of superhydrophobic surfaces with NH_4VO_3 and SiO_2 , *Mater. Lett.* 70, 2012, 105–108.