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Designing Injection Molding Tool with Bio-Inspired Surface

[1]S.NavyaSree, [2]R.Narasimha

[1] (Department of Mechanical,TKR CET,JNTU HYD UniversityINDIA
Email: navyasree.s@gmail.com

[2] (Department Mechanical, Gurunanank institute of technology,JNTU HYDUniversity ,INDIA
Email: narasimha304@gmail.com)

ABSTRACT: *The design of natural surfaces remains a challenging scientific and technological task. The diversity of plant surface structures, evolved over 460 million years, has led to a large variety of highly adapted functional structures. This special biological solutions provides some inspiration for scientists and engineers to design multifunctional artificial materials with multiscale structures. The plant cuticle provides structural, chemical and physical modifications for surface wetting, ranging from superhydrophilic to superhydrophobic. Understanding the physical mechanism of wetting transitions is crucial for the design of those biomimetic surfaces. This paper investigates the process of designing injection moulding tool inspired by hydrophilic structure of the moss. Enlarged hydrophilic structure has been replicated by laser beam machining on cavity insert in a mold base of standard two plates tooling core.*

Key words: *biomimetic, hydrophilic, tool design, injection molding*

I. INTRODUCTION

Replication of workpiece geometries is a well-established method within various manufacturing technologies such as metal casting and plastic moulding. The method involves a mould geometry that is replicated by filling a material into it. Depending on the material characteristics and process control, such a replication process can be more or less successful. Usually the degree of resemblance between the mould geometry and the final workpiece geometry is used as a measure of quality of the replication. As such, the method has been known for centuries using both expendable and permanent moulds. Replication is a recognized technology for mass production. The increased focus on precision manufacturing also is reflected in the demands for replication precision and quality. Material removal processes, where the tool geometry (e.g. cutting edge, electrode geometry, etc.) is determining the workpiece surface features are considered direct surface manufacturing processes [1]. Laser beam machining (LBM) is one of the most widely used thermal energy based non-contact type advance machining process which can be applied for almost whole range of materials. Laser beam is focussed for melting and vaporizing the unwanted material from the parent material [2].

II. BIOINSPIRED SURFACESS

Driven through millions and millions of years has evolved structural diversity and properties of bilogical surfaces by long-lasting game of mutation a natural selection. Different environments led to huge variety adaptations and development of multifunctional, protective interfaces. The diversity is based on the variability of cell shapes, micro and nanostructures on the cell surfaces and by the formation of multicellular structures [3]. Those hierarchical structures with dimensions of features ranging from the macro to nanoscale provide interesting properties. Superhydrophobicity, self-cleaning, drag reduction in fluid flow, molecular-scale devices, energy conversion and conservation, high adhesion and reversible adhesion, aerodynamic lift, fibres and materials with high mechanical strength, biological self-assembly, antireflection, thermal insulation, structural coloration, self-healing and sensory-aid mechanisms are some of the examples found in nature that are major objects of scientific interest [4].

Table 1. Typical biological materials with function integration [5].

Biological materials	Functions
Butterfly wing	Superhydrophobicity, directional adhesion, structural color, self-cleaning, chemical sensing capability, fluorescence emission functions
Brittlestar	Mechanical and optical functions
Cicada wing	Anti-reflection, superhydrophobicity
Fish scale	Drag reduction, superoleophilicity in air, superoleophobicity in water
Gecko foot	Reversible adhesive, superhydrophobicity, self-cleaning
Lotus leaf	Superhydrophobicity, low adhesion, self-cleaning
Mosquito compound eye	Superhydrophobicity, anti-reflection, anti-fogging
Nacre	Mechanical property, structural color
Peacock feather	Structural color, superhydrophobicity
Polar bear fur	Optical property, thermal insulation
Rice leaf	Superhydrophobicity, anisotropic wettability
Rose petal	Superhydrophobicity, structural color, high adhesion
Shark skin	Drag reduction, anti-biofouling
Spicule	Mechanical and fibre-optical properties
Spider capture silk	Water collection ability, mechanical property, elasticity, stickiness
Spider dragline silk	Mechanical property, supercontraction, torsional shape memory
Water strider leg	Durable and robust superhydrophobicity

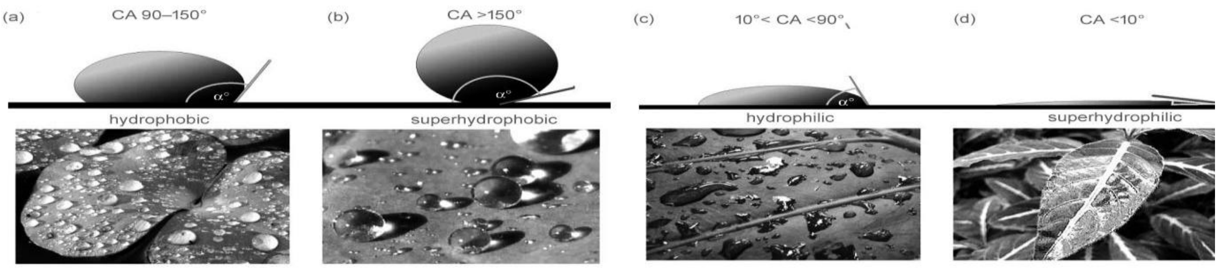


Fig.1. Four classes of surface wettability and representative leaves examples: a) hydrophobic, b) superhydrophobic , c) hydrophilic , d) superhydrophilic [3]

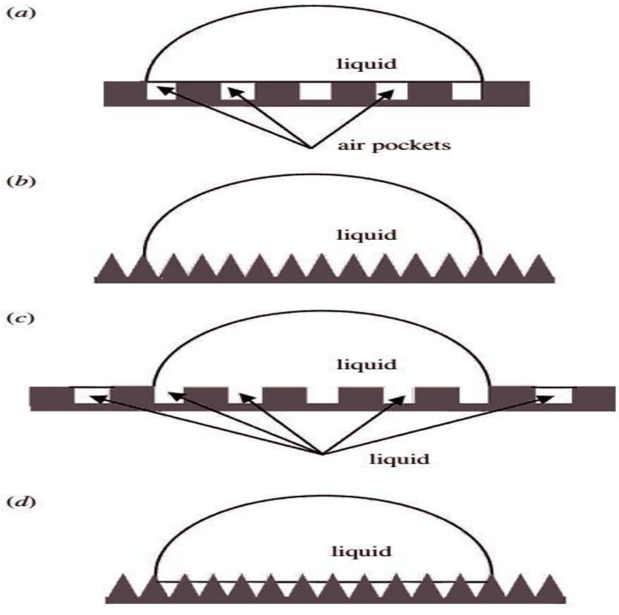


Fig.2. Various wetting states occurring on rough surfaces: (a) Cassie air-trapping state, (b) Wenzel state, (c) Cassie impregnating wetting state and (d) mixed wetting state [6]

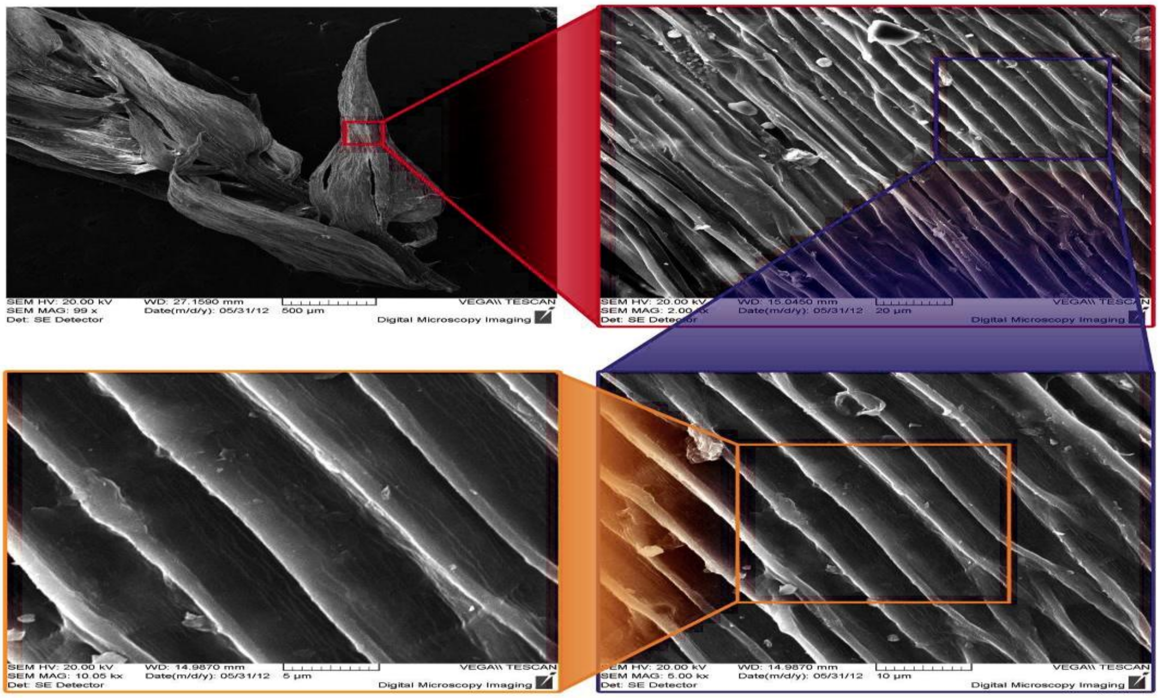
Hierarchical micro and nanostructures of plant surfaces are also relevant for surface wettability. During the last years has been given a lot of attention to the superhydrophobic and self-cleaning properties of plant surfaces, but in plants also water-spreading (superhydrophilic) surfaces. Wetting of surfaces is related to surface structuring and surface chemistry. Wetting is process of liquid interaction at solid–gas interfaces. It describes how a liquid comes in contact with a solid surface. The main method for the characterization of the wettability of surfaces is contact angle (CA) measurement. Contact angle is the unit for the surface wettability.

A high CA describes surfaces on which a water droplet forms a spherical shape, and the real contact between the adhering droplet and the surface is very small. Wettable surfaces, on which an applied drop of water tends to spread, have a low CA. The wetting behaviour of solid surfaces can be divided into four classes, defined by their static CA (Fig. 1). The CA of a liquid on a surface depends on the surface tension (molecular forces) of involved liquid, solid surface and surrounding vapour. Thus, wetting depends on the ratio between the energy necessary for the enlargement of the surface and the gain of energy due to adsorption [3].

Based on lessons from nature, one of the ways to increase the hydrophobicity is to increase surface roughness. Due to this roughness-induced hydrophobicity has become a major object of scientific interest. Superhydrophilic surfaces are if the contact angle is below 10°. Plant surfaces can either absorb water or let water spread over its surface. Surface roughness on a hydrophilic or hydrophobic surface decreases or increases the contact angle, respectively, based on the so-called Wenzel effect. Air pocket formation in the valleys can increase the contact angle for both hydrophilic and hydrophobic surfaces based on the so-called Cassie–Baxter effect. Formation of air pockets, leading to a composite interface, is the key to very high contact angle and low contact angle hysteresis [4].

III. DESIGNING PROCESS

Firstly has been captured micrographs using scanning electron microscope (SEM) (Fig. 3) on representative moss specimen. By investigation of natural pattern has been suggested hierarchical structure for replication (Fig. 4). This structure has been consequently transferred by the laser beam machining to the cavity insert in a mold base of standard two plates tooling core (Fig. 5). Used laser beam machining technique provided still that smallest possible manufacturable surface 40x enlarged compared to real natural surface structure. Due to this was suggested testing specimen with four different types of enlarged hierarchical structures for replication. Consequently were injected on injection molding machine termoplastic testing specimens from PP, ABS, PA.



Chemically speaking, PA with its amide bonds is a polar polymer, resulting in its typical water absorption. ABS, on the other hand, is a non-polar polymer like PP. Because of non - polar character of PP and ABS paid for years as unvarnished plastics.

Fig.3. SEM micrographs of moss hydrophilic surface structure.

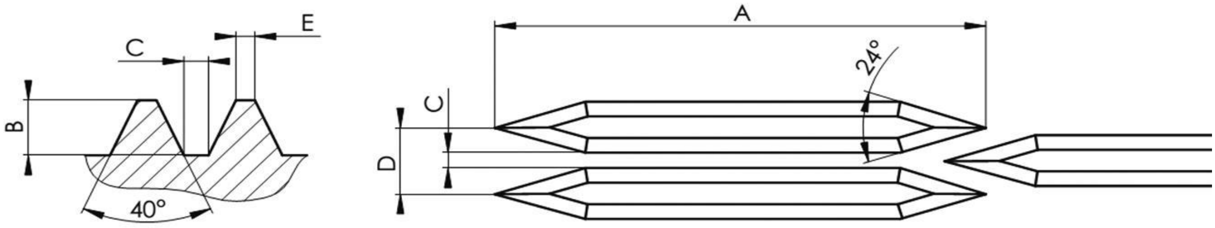


Fig.4. Design of hierarchical surface structure for replication by laser beam machining

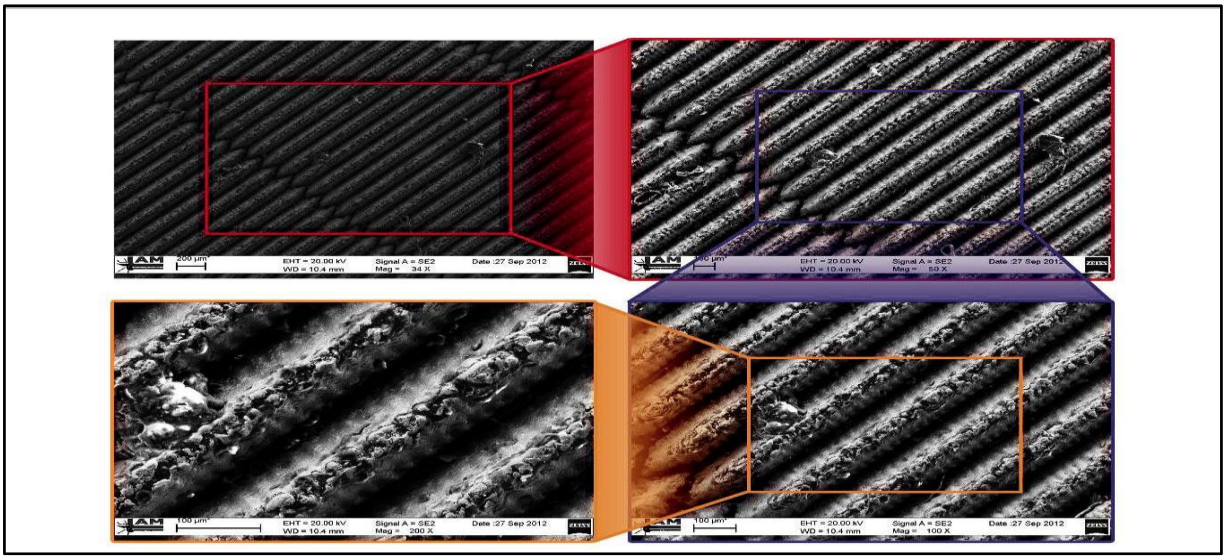


Fig. 5 SEM micrographs of laser beam machined hierarchical surface of cavity insert

IV. CONCLUSION

Surface structuring based on natural patern allows surface functionalisation by means of surface geometrical modification without back end processing (coating or further treatments) or it can for example improve varnishability of non-polar polymers. Given a micro/nano pattern on a mould master, various tailored properties can be attributed to the replicated substrate. Bio-inspired special wettability is a promising field in materials and surface science. Testing specimens from all suggested polymers were successfully injected. Problem caused at demoulding phase due to increased surface volume was solved by using mould separators. Further investigation will be focused on evaluation of wetting transitions on injected testing specimens according to varnishability of non-polar polymers. Investigated will be methods for replication structures in exactly same size like natural pattern. For example replication techniques like soft and nano lithography. Laser nano-manufacturing is a promising and rapidly growing field but the research is still at basic phase. Many opportunities for research and development exist.

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