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# Surface tailoring of aluminum sheets by PVD sputtering

Fabrizio Quadrini*, Denise Bellisario, Giovanni Matteo Tedde, Gustavo Santolim, Loredana Santo

*Department of Industrial Engineering, University of Rome Tor Vergata, Via del Politecnico 1, 00133 Rome, Italy*

**Abstract**

In order to change surface morphology of aluminum sheets, they have been mounted as targets in a PVD sputtering system, and subjected to several sputtering cycles. As an effect of the plasma erosion, sheet surface continuously changes during multiple sputtering cycles. First results are shown in terms of surface morphology. The levelling effect of the plasma erosion is evident as initial irregularities from rolling partially disappear, and surface profiles become smoother by increasing number of cycles. That is the first result in the direction of surface tailoring, and nano-grooves could be expected at very high numbers of cycles. Surface nano-tailoring would be the first step for the production of patterns in injection molding of common polymers.


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*Keywords:* Aluminum sheets; surface texturing; PVD sputtering

## 1. Introduction

The present study is the first step toward the production of a hierarchical surface by molding of organic compounds. A hierarchical surface is characterized by different morphological levels, generally two: one in a micro-scale and the other in a lower micro- (or nano-) scale. A typical example is a surface with cylindrical micro-pins (first level) and nano-pins (second level) over the external surface of the micro-pins [1]. Hierarchical surfaces come from the observation of the Nature where micro/nanostructures have developed as the result of millions of years of evolution. The interest of the scientific world toward hierarchical surfaces is continuously increasing: more than 6800 new contributes can be found in scientific database (Scopus font) in the last 5 years, the double in comparison with the previous 5 years. Thanks to technological innovations in surface engineering, many solutions have been

* Corresponding author. Tel.: +39 06 7259 7167; fax: +39 06 2021351.
*E-mail address:* fabrizio.quadrini@uniroma2.it


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found to change surface topography in micro and nano-scale. This knowledge has been used for mimicking hierarchical surface morphology of natural structures, mainly the lotus leaf [2]. In manufacturing, the research challenge is making hierarchical surfaces by mass-production technologies above all for polymers, elastomers [3] and thermoplastics [4]. Superhydrophobicity and superhydrophilicity can be obtained both by injection molding of conventional polymers such as polypropylene [5] without affecting wear properties [6]. As a result polypropylene could be used for efficient self-cleaning and microfluidic manipulation [7]. This fact opens a very wide application scenario, from aerospace to biomedicine. In fact, the importance of surface hierarchy in medicine is deeply discussed in scientific literature but it has been never evaluated for polymers. In bone tissue engineering, hierarchical surfaces on ceramic [8] and hybrid [9] substrates have been evaluated for cell growth and differentiation also with 3D scaffolds [10]. In other cases, hierarchical surfaces can exalt antibacterial [11] and anti-biofouling [12] properties of non-organic materials such as titanium. By tailoring surface morphology, it is possible to control cell growth and differentiation of stem cells [13] on the same materials (titanium substrates) where antibacterial behavior can be exalted. At this point, it is evident the lack of scientific background about using organic substrates with hierarchical surfaces for biomedical purposes, even if polymers are optimal candidates for this application. It is known that surface morphology of polymeric substrates can influence cultured human cells [14] but the option of the surface hierarchy has not been considered yet.

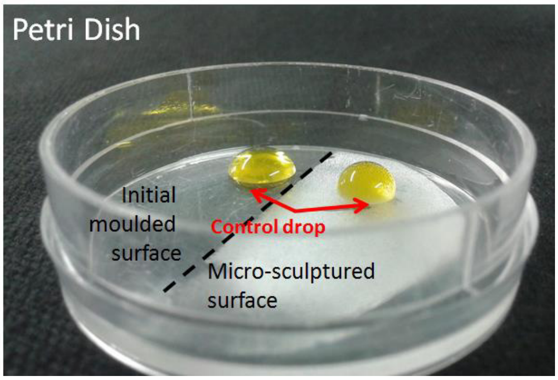


Fig. 1. (a) first picture; (b) second picture.

Textured polymeric surfaces have to be produced by molding and, therefore, a mold with a negative textured surface is necessary. Typical manufacturing technologies of plastic materials are injection molding and compression molding, in both cases an aluminum alloy or steel mold is used. Aluminum alloy is used in the case of low production runs or for prototyping activities because of the easiness of mold production but low durability.

During molding, organic surfaces are made by replication of the mold metal surfaces. Therefore the first step is understanding if those surfaces can be tailored. At present, the demand on new technologies for surface texturing of metals is still pressing, above all in the nano-scale and in the optic of an industrial use. In this study, the possibility to change the surface morphology of aluminum sheets by means of PVD (physical vapor deposition) sputtering has been evaluated. Generally, surface sculpturing of polymeric substrates in micro-scale is not complex, and the effect on the surface properties is evident. At the beginning of this study, some results were easily obtained in terms of surface change even if hierarchical surfaces have not be applied yet. An example is given in Fig.1 where a polymeric surface of a Petri dish (made of polystyrene) has been modified by over-molding with a sintered pattern: the consequence is a remarkable change in the contact angle. Unfortunately, because of the micro-sculptured surface, transparency of the dish is lost as well as its function. If nano-sculpturing or hierarchical approach would be possible, the dish transparency could be preserved with the advantage of giving new functionality to the same surface. Based on this simple consideration, research started with the goal of producing metal patterns with tailored surfaces. The final goal is nano-texturing and, for this reason, new technical solutions were investigated to allow surface change in that scale. In PVD sputtering, an Argon plasma is formed and ions are accelerated toward a target.

Due to the ion bombardment, the target material is forced to evaporate and this vapor is typically used to uniformly coat substrates. On the other hand, the target is progressively eroded and cavities and groves can be formed as a function of the current distribution and process conditions. The basic idea is using aluminum sheets as patterns in a sputtering process so as to evaluate the surface change because of ion erosion.

**Nomenclature**

| | |
|---|---|
| $R_a$ | arithmetic average of absolute values |
| $R_t$ | maximum height of the trofile |
| $R_{Sm}$ | mean spacing between peaks |
| $R_{Dq}$ | root mean square slope of the profile within the sampling length |
| $R_{sk}$ | skewness |
| $R_{ku}$ | kurtosis |

## 2. Materials and Methods

Aluminum alloy sheets (6082 T6, 30x30x1) have been used for sputtering tests, being mounted as targets of a small sputtering system (S150A Sputter Coater by Edwards). During sputtering, a current of 30 mA was set, which corresponded about the maximum allowable voltage (2.5 kV). Aluminum is a difficult material to sputter because of the need of very high voltages. Therefore, a weak erosion yield was achieved and many sputtering cycles were necessary to change the sample surface. Each single cycle was 6 min long and the time between two cycles was used to cool down the system. Generally, consecutive cycles were made without opening the sputter chamber so as to reduce the effect of oxidation, apart from 5, 10, 20 and 40 cycles at which surface measurements were carried out.

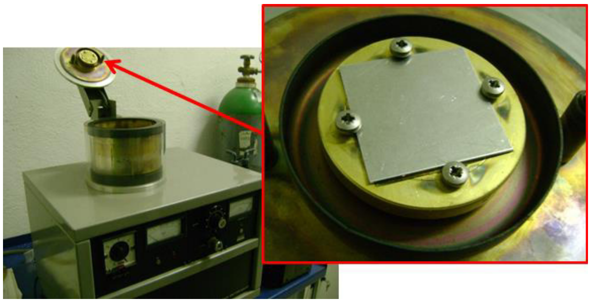

Fig. 2. PVD sputtering system for target erosion.

Contact gauge Taylor Hobson Surface Topography System (TalySurf CLI 2000, Taylor Hobson, Leicester, UK) in small range mode (0.1 mm) with a resolution of 2 nm was used to analyse the surface morphology of the samples. About 1000 surface profiles (1 mm long) were recorded for each measurement so as to cover a 1 $mm^2$ area at a scanning speed of 500 μm/s. Profiles were acquired in a direction normal to the rolling direction of the sheets, clearly visible also at naked eye. Amplitude, spacing and hybrid parameters were calculated by usng TalyMap 3.1 (by Taylor Hobson) with a 0.08 mm Gaussian filter.

## 3. Results and discussion

The effect of consecutive sputtering cycles on the surface morphology is shown in Fig.3. Due to the erosion by plasma, the surface is levelled. The morphology coming from the rolling process progressively disappears. This effect is also confirmed by the analyses of single profiles (Fig.4). However, a quantitative analysis is necessary to provide a better comparison between the different conditions.

Figure 5 shows the trends of the amplitude, spacing and hybrid roughness parameters for the sheets after different number of sputtering cycles. Average roughness $R_a$ can approach low values as 0.095 μm and 0.079 μm, after 20 and 40 sputtering cycles, respectively, which are lower than the values before sputtering cycles (0.13 μm). Moreover there is a reduction also in the dispersion of Ra values by increasing cycles (Fig.5).

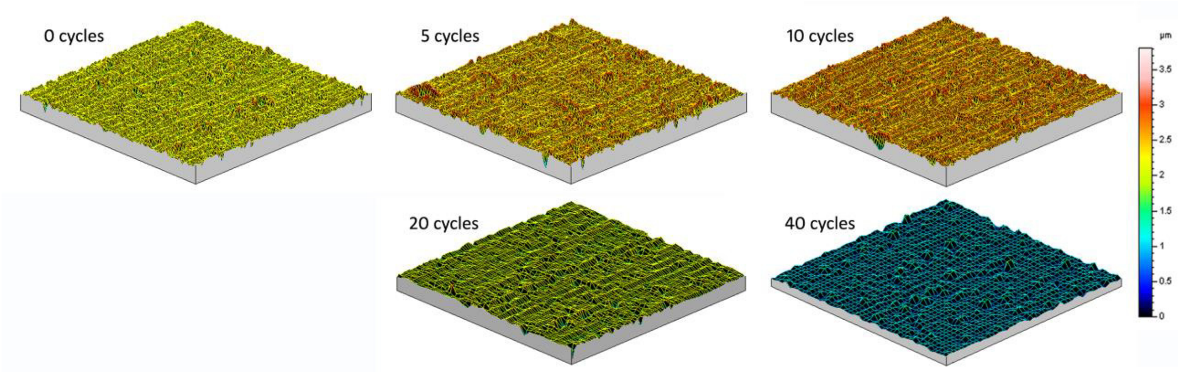


Fig. 3. Surface maps at increasing number of sputtering cycles.

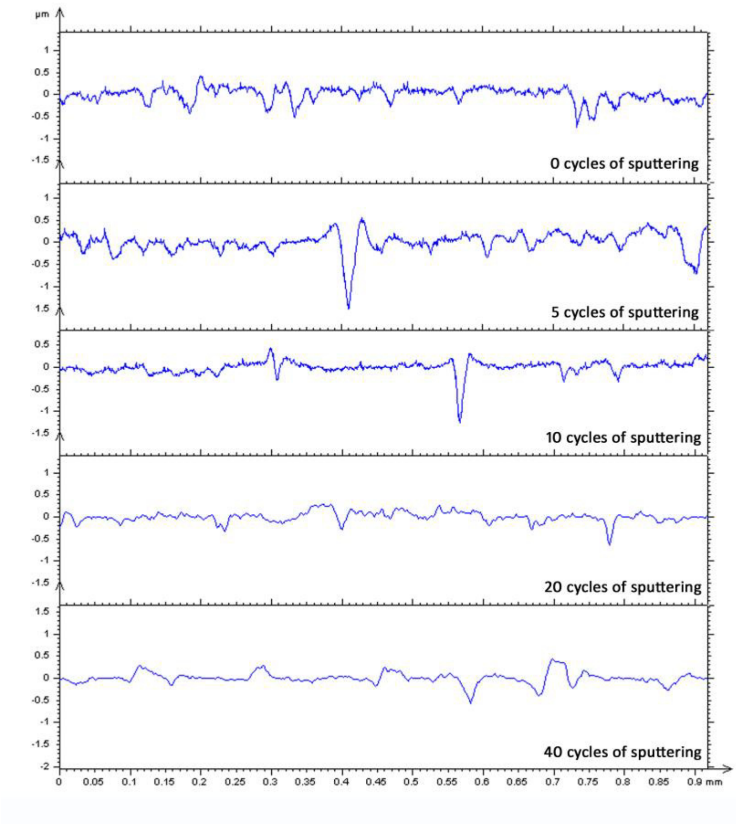


Fig. 4. Single profiles at increasing number of sputtering cycles.

Flattening of the surface morphology due to sputtering is also stated by the increase in the modulus of spacing and hybrid roughness parameters. In particular, skewness $R_{sk}$ tends to assume positive values after 40 cycles of sputtering, that corresponds to profiles with valleys filled in or high peaks (Fig.6). The skewness of a profile is the third central moment of profile amplitude probability density function, measured over the assessment length. It is used to measure the symmetry of the profile about the mean line. This parameter is sensitive to occasional deep valleys or high peaks. The surface profiles become even more symmetrical around the mean line and this is more likely ascribable to the random subtraction of Al atoms.

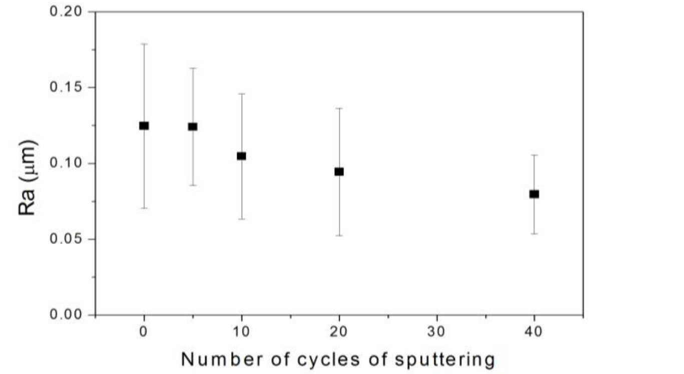


Fig. 5. Effect of sputtering cycles on $R_a$.

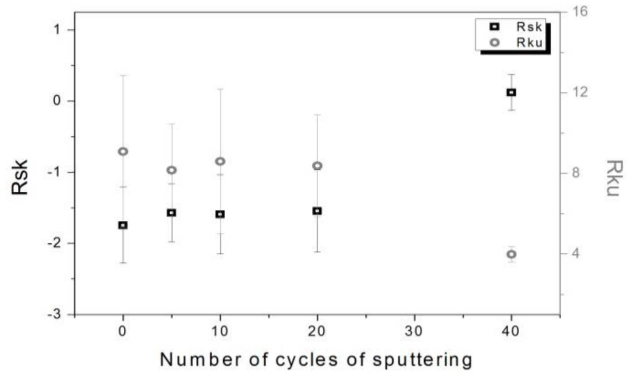


Fig. 6. Effect of sputtering cycles on $R_{sk}$ and $R_{ku}$.

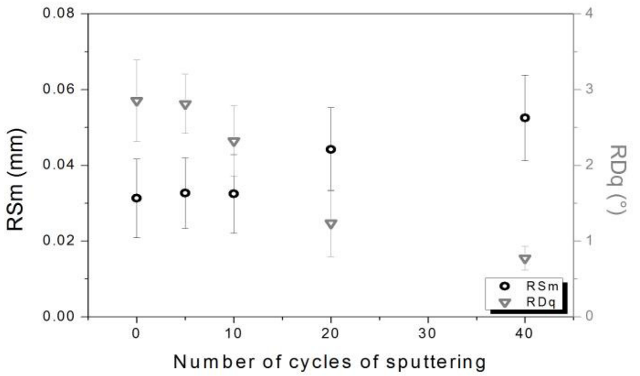


Fig. 7. Effect of sputtering cycles on $R_{Sm}$ and $R_{Dq}$..

Similarly, Kurtosis $R_{ku}$ decreases. Kurtosis coefficient is the fourth central moment of profile amplitude probability density function, measured over the assessment length. It describes the sharpness of the probability density of the profile. The profiles of the sample before sputtering is higher than 3, the distribution curve is said to be leptokurtoic, and has relatively many high peaks and low valleys. After 40 cycles of sputtering, $R_{ku}$ is closer to 3 thus supporting the basic idea that the profiles becomes more platykurtic, with relative few high peaks and low valleys. The mean spacing between peaks at the mean line ($R_{Sm}$) increases as the number of sputtering cycles (Fig.7). $R_{Sm}$ is 0.03 mm at the beginning and after 40 sputtering cycles becomes 0.05 mm. Furthermore, the roughness inclination angle $R_{Dq}$ of the profiles decreases by increasing the number of sputtering cycles.

## 4. Conclusion

This study is the first step toward the definition of a new technical solution for surface tailoring. Sensibility of aluminum targets to PVD sputtering has been evaluated and results show that surface tailoring is possible at least in terms of surface leveling. The mechanism at the basis of the roughness change is still under evaluation and further analyses are necessary. It is possible that this change is related to the levelling action of the plasma ions which impact surface peaks Next step will be understanding if nano-groves can be obtained at very high number of sputtering cycles, if not yet present. Probably, different sputtering systems are necessary because of the low performance of aluminum sputtering or different target materials.

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