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The effect of sandblasting on surface properties for adhesion

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ABSTRACT

The paper presents the effect of sandblasting on surface properties of steel for adhesion. The investigated parameters included pressure (1, 2 and 4 bars) and four types of abrasive material, each material type being of different granulation. In the experiments the effect of the above variables on the surface roughness, contact angle Θ, work of adhesion W_a and surface free energy γ was investigated. It has been shown in this research that surface properties are more affected by abrasive material type applied rather than by the sandblasting process parameters.

1. Introduction

Surface treatment is one of the most important factors governing the strength of adhesive joints [1–5]. There are numerous methods of pre-treatments of joining materials [6–9]. The most common treatments are mechanical, chemical and electrochemical methods. The mechanical methods consist of roughening processes by, for example, grit-blasting, sandblasting or abrasion [4,10–12].

Roughening surfaces prior to bonding generally enhances adhesive joint strength. An increase of adherend roughness should lead to an increase of effective area for the bond [13]. However, it is reported that excess roughness decreases the ability for adhesive penetration, increasing void formation and therefore introducing localized stress concentration [14,15]. Indeed, a decrease of strength is often found when the adherend surface is too rough. The value of critical roughness depends on many parameters, such as, for example, the roughening pre-treatment applied, the type of adherend, the type of adhesive, the geometry of the joint and the stresses applied. It has also been found that roughening may introduce physico-chemical changes, which affect wettability and surface free energy [1]. Surface roughness can also affect the spreading of the adhesive, either because the adhesive cannot penetrate the adherend or because it gels before it completes the penetration. The relationship between roughness and adhesion is not very simple. Optimum surface profile varies from one adhesive to another, and depends upon the type of stress applied [16].

The effect of surface roughness on wettability has been studied by many researchers using surface roughness factors such a the Wenzel roughness factor [17,18]. The effect of density and height of peaks on adhesion fracture strength has been discussed by Kunio and Mitsuru [19]. The effect of grit-blasting on surface properties for adhesion has been presented by Harris and Beevers [12]. The same issue of surface pre-treatment on an aluminum surface has been investigated by Prolongo and Urena [14]. Shahid and Hashim [20] examined the influence of surface roughness of a steel adherend on cleavage strength. Hay et al. [21] presented some information on the influence of surface roughness on wettability.

Sandblasting is the operation of forcibly propelling, under high pressure, a stream of abrasive material against a surface in order to clean the surface or influence its shape. Sandblasting is recommended to be used prior to the application of a paint coating to a surface. The first sandblasting process was patented by Benjamin Tilghman in 1870 [22]. Sand is the most commonly used abrasive material, yet other fine materials can be used, including copper slag, shot, glass, metal, dry ice, garnet (mineral), as well as bits of coconut shell or other plants.

Sandblasting is often recommended to be applied to surfaces of various structural materials prior to adhesive bonding, these materials including steel [23], titanium or titanium alloys [24,25], aluminum alloys [4,13] and polymers (polyester, polyethylene) or composites [26,27]. Bresson et al. [13] investigated the different conditions of sandblasting: the pressure and also the type of grit. Some information of description of sandblasting test is presented in [20,25,26,28].

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Although sandblasting produces effects similar to those of grinding, sandblasted surfaces are less rough and more uniform compared to those subjected to grinding operations. In addition sandblasting can be applied to surfaces of irregular shape. Roughness of adherend surfaces has frequently been used as design parameters for adhesive joints [20,21,29,30].

The purpose of this work was to study the effect of sandblasting parameters on the surface properties of steel and thus identify the surface characteristics vital for optimum adhesive joint strength performance.

2. Analysis

For ideal surfaces, which are considered to be rigid, smooth (surface roughness «0.5 μm) and chemically homogeneous [31–33], there exists only one contact angle, which is the true equilibrium contact angle [34,35]. However, for real surfaces, there may be several observed contact angles (advancing and receding contact angles), which results in contact angle hysteresis [36–41].

2.1. Contact angle hysteresis

When a liquid drop is placed on a solid, it spreads until it attains an equilibrium state. If additional liquid is added to the drop, the contact line advances and stops. The drop exhibits an advancing contact angle Θ_a in the cases of each time motion (Fig. 1a). If liquid is removed from the drop, the contact angle decreases without movement of the contact line. If enough liquid is removed, the contact line retreats. The drop exhibits a receding contact angle Θ_r. The difference between Θ_a and Θ_r is referred to as contact angle hysteresis [37].

Contact angle hysteresis H (1), exists when there is inequality of the advancing angle Θ_a and receding contact angle Θ_r [38]

$$H \equiv \Theta_a - \Theta_r \tag{1}$$

Contact angle hysteresis is most often defined empirically as arithmetic difference (2) [37],

$$\Delta\Theta = \Theta_a - \Theta_r \tag{2}$$

And a ratio H (3), has been used to denote the hysteresis for a surface [39].

$$H = (\Theta_a - \Theta_r)/\Theta_a \tag{3}$$

The advancing contact angle is less sensitive to surface roughness and heterogeneity than the receding contact angle. Therefore, advancing contact angle data are commonly used to calculate surface and interfacial tension components [42,43].

The advancing angle Θ_a and receding contact angle Θ_r are often defined in dependence on the triple line motion on formerly non-wetted or wetted area. This kind of definition is dependent on the image resolution, the frame rate and the conditions used for the optical identification of the drop shape [44].

Contact angle hysteresis has been attributed to solid surface roughness, surface chemical heterogeneity, penetration of liquid into solid surface, swelling, and also surface reorientation of functional groups [45–47]. Surface roughness is not expected to result in contact angle hysteresis for relatively smooth surfaces (roughness surfaces less than approximately 0.5 μm) [38].

2.2. Work of adhesion W_a

The work of adhesion W_a describes the work required to create a surface unit due to separating the measuring liquid and tested material. W_a can be defined by the following Eq. (4) [17,48,49]:

$$W_a = \gamma_L(1 + \cos\Theta) \tag{4}$$

The Young-Dupree equation is fulfilled if the contact angle depends only on the solid surface tension but not roughness and ranged from 180 to strictly zero degree. If spreading of the liquid over solid surface is observed it is difficult to state that this equation is fulfilled.

Most existing theoretical models assume that imperfections such a roughness or heterogeneities, cause hysteresis of contact angle [17,36,40,41,50]. One approach is to ignore the details of the interface and use a thermodynamic approach to describe hysteresis [37]. A model based on Young's equation has been used to calculate the work of adhesion from contact angle hysteresis ΔW [37,51,52],

$$\Delta W = \gamma_L(\cos\Theta_r - \cos\Theta_a) \tag{5}$$

where:

γ_L – the surface free energy of contact liquid,
Θ_r – receding contact angle,
Θ_a – advancing contact angle.

The work of adhesion from the contact angle hysteresis ΔW (Eq. (5)) value agrees reasonably well with the hysteresis in solid-solid surface energy measurements for finite contact angles on low-energy surfaces [53,54].

2.3. Wetting and wetting criteria

Wetting of liquids on solid surfaces is a topic of fundamental interest with widespread technological implications, for example during bonding. Adhesives with surface energies less than that of an adherend will readily wet the surface and form good bonds. The adhesive will spread on the adherend when the surface free energy of the adherend is greater than that of the adhesive [17]. If sufficiently intimate contact is achieved between the adhesive and adherend a physical interaction develops between the atoms of the two surfaces, which results in wetting.

Wetting may be due to: van der Waals forces (dipole–dipole and dispersion forces), acid-base interactions and weak hydrogen bonding [17]. The extent of wetting depends on the differences in

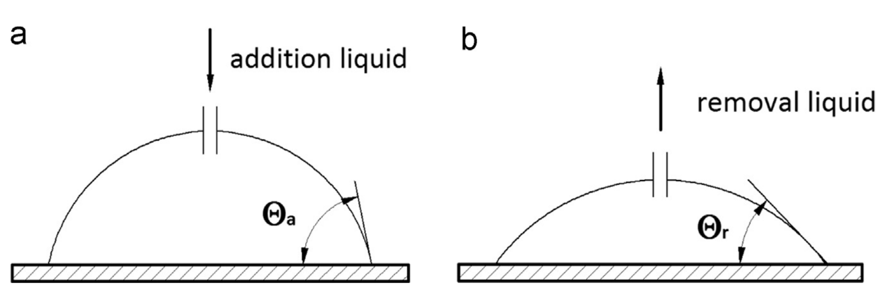

Fig. 1. Side view of a sessile liquid drop on the solid surface: (a) advancing contact angle Θ_a and (b) receding contact angle Θ_r.