

Emerging Technologies for Use in Aerospace Bonded Assemblies

Richard J. Crossley, Svetan Ratchev, and Anthony Smith
University of Nottingham

ABSTRACT

Several new technologies are now emerging to improve adhesive supply and formulation along with surface treatments that have the potential to offer significant improvements to both surface energy and cleanliness [3]. Additionally, the miniaturisation of laboratory techniques into portable equipment offers potential for online surface energy and chemical analysis measurement for use as quality control measures in a production environment. An overview of newly available technology is given here with several devices studied in further detail.

Technologies assessed further in this paper are; portable surface contact angle measurement, ambient pressure plasma cleaning, portable FTIR measurement and adhesive mixing equipment. A number of potential applications are outlined for each device based on the operational technique. The practical aspects of implementation and the perceived technology readiness levels for operation, implementation and results are also given.

Some initial studies have also been carried out into the effectiveness of each device. Ambient pressure plasma cleaning has been assessed for its ability to remove contaminants and improve surface energy. Miniaturised Sessile droplet test equipment has also been assessed for quality and repeatability of results. Portable FTIR has also been assessed for its sensitivity in a number of applications. All aforementioned equipment has also been assessed with regards to associated practicalities of use, measurement cycle times and required operator skill level.

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INTRODUCTION

Bonded assemblies offer the opportunity to greatly reduce drilling, riveting, fastener content, finishing and sealing operations. Therefore, significant labour and cost savings can be achieved provided the quality and strength of the bond is sufficient and reliable [1]. The reliability and strength of a bond is dependent on the adhesive formulation, adhesive layer thickness, surface contamination, surface finish and the integrity of any finishing coatings if applicable. At present several aircraft manufacturers continue to rivet or bolt structural adhesive assemblies due to an inability to guarantee optimum bonding conditions in a production environment [2]. Typical production obstacles appear to be; an inability to guarantee clean surfaces due to contaminants, difficulty in maintaining repeatable bond line thickness, unknown cavitation due to trapped air, and fluctuations in final cure state due to supply, mixing and environmental variations.

The overall strength of a bond is generally dependent on the strength of molecular layers which exists between the two

load bearing substrates and also to the strength of interfaces between each layer, the weakest of which typically determines the overall bond strength. A perfect assembly bond would consist of two interfaces either at a metallic or primed surface and an adhesive layer which is sufficiently thick to prevent substrate contact at the peaks of surface roughness. The maximum strength of which would be attributed to the lower of the interfacial strength or the cohesive strength of the resin layer, provided the effects of mechanical interlocking are negligible. However, this is rarely the case in practice due to the presence of contaminants which can either reduce interfacial strength or, if sufficiently thick, can create a weak layer. Therefore, for the typical assembly bond, the following issues are of most importance:

- *Accuracy of adhesive mixing*, since the adhesive formulation will determine the adhesive layer strength.
- *Time of application (resin viscosity)*, as the adhesive cures its viscosity increases which may prevent adequate wetting of the surface, reducing interface strength

- *Surface contaminants*, may reduce the interface strength or create a cohesively weak layer.
- *Bond line thickness*, ensuring that dry contact or cavities do not occur

Several new technologies are now emerging to improve adhesive supply and formulation along with surface treatments that have the potential to offer significant improvements to both surface energy and cleanliness [3]. The miniaturisation of laboratory techniques into portable equipment offers potential for online surface energy treatment, measurement and chemical analysis for use as quality control measures in a production environment (Figure 1).

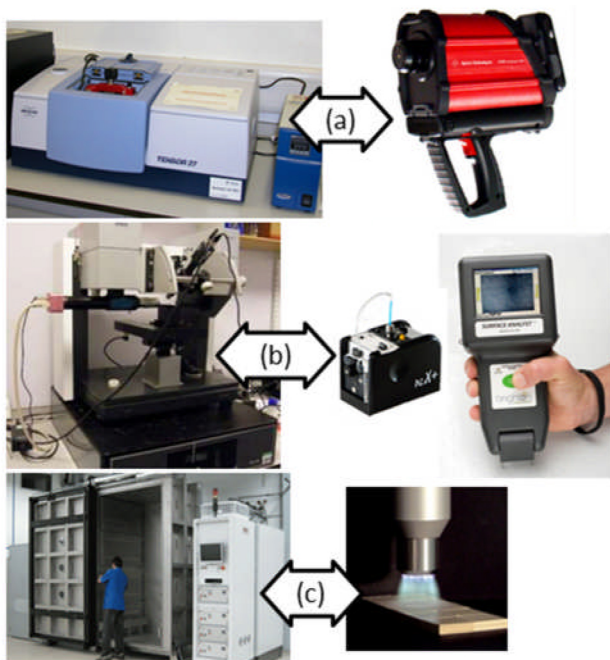


Figure 1. The miniaturisation of (a)FTIR, (b)Surface energy and (c)plasma treatment equipment to allow potential for online production use

Technologies assessed further in this paper are; portable surface contact angle measurement, ambient pressure plasma cleaning, portable FTIR measurement and adhesive mixing equipment. A number of potential applications are outlined for each device based on the operational technique. The practical aspects of implementation and the perceived technology readiness levels for operation, implementation and some initial results are also given. Ambient pressure plasma cleaning has been assessed for its ability to remove contaminants and improve surface energy. Miniaturised Sessile droplet test equipment has also been assessed for quality and repeatability of results. Portable FTIR has also been assessed for its sensitivity in a number of applications. All aforementioned equipment has also been assessed with regards to associated practicalities of use, measurement cycle times and required operator skill level.

SURFACE ENERGY MEASUREMENT

Surface energy measurements are typically carried out by means of a Sessile droplet test, where an accurately measured micro litre sized droplet of liquid is dropped onto the surface under investigation. The contact angle of the droplet is measured accurately using high resolution cameras and relates to the surface energy using the Young's equation [4]. Typically, a lower contact angle relates to a higher surface energy and improved wettability (Figure 2). However, this would only translate to an improvement in bond strength if the bond is limited by a poor interface.

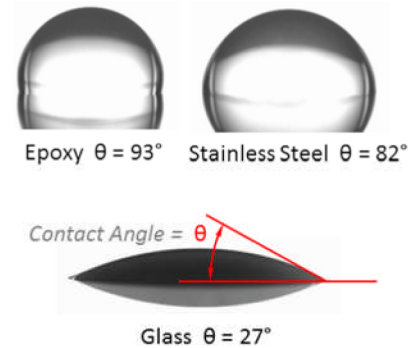


Figure 2. Contact angle as a measure of surface energy showing a low energy epoxy surface with residual mould release, a stainless steel surface and a high energy clean glass surface.

The increased quality, reduced size and cost of digital camera technology has allowed for the miniaturisation of the test in the form of various hand held devices (Figure 1a). Their operation varies between models but generally each requires clear access to the surface for the footprint size of the instrument. Ideally the surface would be flat but some curvature, typically not greater than $R=50\text{mm}$, is allowed. Some models require that the surface is horizontal while others allow for measurement at a range of angles, although independent assessment of gravitational effects would be recommended.

Equipment and Method

The PG-X pocket goniometer with deionised water and a $4\mu\text{L}$ droplet size has been used for contact angle measurement throughout this paper with temperature and relative humidity fluctuations not exceeding $\pm 0.5^\circ\text{C}$ and 5% R.H. respectively.

Equilibrium Time

The instrument can typically take single or dynamic measurements. For single measurements the droplet is allowed to settle for a period determined by the user which is not recorded. In dynamic mode, measurements begin immediately with the formation of a recognisable droplet and continue in logarithmic periods up to 5-10 minutes. It can be seen that for a range of surfaces the contact angle is

dependent both on the surface energy of the material and the time at which the reading is taken. The contact angle of some surfaces has been observed to drop by as much as 10° requiring at least 20 seconds to approach equilibrium (Figure 3).

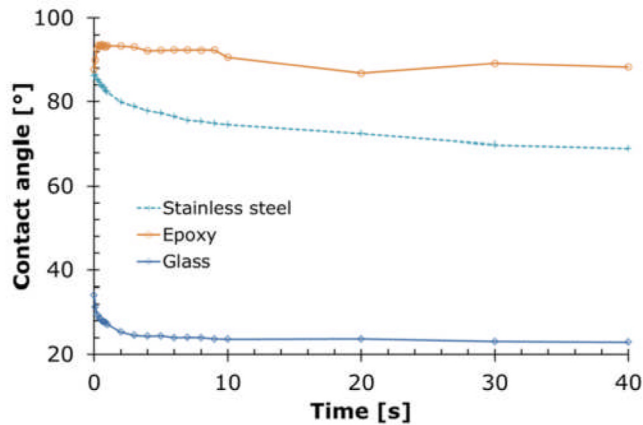


Figure 3. Contact angle as a function of time from initial droplet formation

Fluid Type, Surface Finish and Variability

In addition to water, fluids such as polyethylene glycol (PEG-400) and polyisoprene Isolene 40 have been used and found to vary the contact angle significantly on hydrophobic and hydrophilic surfaces [5]. However, for this study water was utilised in isolation as it is likely to be the preferred fluid in a production environment due to its good availability, low reactivity, low toxicity and ability to be removed easily from the surface after testing.

Surface finish is also believed to affect contact angle [6] perhaps due to capillary effects. The measurement process may also be inadvertently affected as it is more difficult for automated software to define a clear edge and therefore contact angle with an excessively rough or undulating surface.

Despite these considerations a definitive effect on contact angle could not be found with stainless steel surfaces with a significant degree of variation in surface roughness. The results showed a maximum effect of 10.4° exceeding an overall standard deviation of 2.3° , although no trend was observed (Figure 4) and the greatest effect was observed on the non-abraded plate and could therefore be the result of residual contaminants not completely removed during the cleaning process. Surface roughness was therefore not considered to have a significant effect on measurements. An overall standard deviation for the range of surfaces of 2.7° was recorded slightly higher than the 2.3° recorded during the surface roughness experiments also indicating that surface roughness did not affect measurement variability in this case.

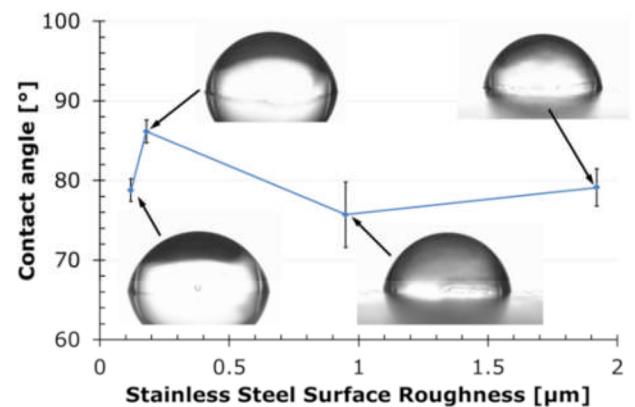


Figure 4. The effect of surface roughness on the contact angle of a stainless steel plate

Contaminants

The presence of contaminants commonly found in a production environment can also be detected. However, they do not necessarily show a reduction in surface energy, perhaps due to absorbance if the contaminate leaves a powdery dry residue (Table 1). Additionally, the droplet must fall over the contaminant making comprehensive testing of large scale areas impractical and time consuming.

Table 1. The water contact angle of contaminate films on a Zinc Chromate primed surface

Zinc Chromate Primed Plate	Contact angle at 10 sec	Droplet image
Alcohol cleaned	94°	
Dried cutting fluid	35°	
Finger print	82°	
Silicone grease	119°	
Synthetic grease	112°	

Application in Aerospace Production

Typically a water break test may be carried out in accordance with ASTM F22-02(2007) where a water film is allowed to run over the surface. Breaks and beading of the