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The Effect of Hydraulic Bulge Process on the Surface Topography of Annealed AISI 304 Stainless Steel

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Abstract

In this study, the relationship between surface topography and strain was established for annealed 0.2 mm thick AISI 304 stainless steel sheet that had been hydroformed. The effect of the die diameter on the surface topography was also examined. Sheets were bulged using stepwise application of hydraulic pressure; forcing the sheet metal through 5 mm and 11 mm diameter open dies. The strains at the pole of the bulge of the work pieces were determined analytically using the Jovane analytical method, this was achieved by measuring the height of the pole of the bulge for every applied hydraulic pressure for a particular die. The surface topography at the micro level was found by scanning the bulge of the sample using an atomic force microscope over an area of 60 μm x 60 μm. The results of this study indicate that the bearing ratio was unaffected by the change in strain for both the 5 mm die and the 11- mm diameter dies and that roughness decreases as the diameter decreases for similar strains. The average, root mean square, peak-to-peak roughness and the maximum depth of the surface profile show a linear relationship with the strain

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1. Introduction

Hydroforming is a metal fabricating and shaping process, which allows the shaping of metals such as steel, stainless steel, copper, aluminium, and brass [1]. Hydroforming is a cost-effective and specialized type of metal forming that utilizes highly pressurized fluid to form metal. The process both in macro- and microscale has found many applications such as: 1) mechanical testing of materials, referred to as bulge testing; 2) energy applications such as fuel cell bi-polar plates and fluid cells; 3) biomedical applications such as forming of micro-tubes for medical devices; and 4) automotive and aerospace manufacturing. The decision to adopt hydroforming for these applications can be attributed to the precision and intricate part forming capabilities of hydroforming. Other qualities and benefits provided by hydroforming processes are well documented such as seamless bonding, high quality surface finish, increased part strength, and increased strain to fracture [2]. Figure 1 shows the top view and side view of an 11 mm diameter bulge part that was used to determine the material properties for the current study.

Hydroforming has been shown to produce better surface characteristics than other forming operations such as stamping and other deep drawing operations. For these operations, the interaction between sheet metal, and the male and female dies produce draw marks which are eliminated in hydroforming. It has been found that surface roughness plays an important role in functionality for such applications as PEMFC bi-polar plates where it is necessary to consider material properties such as corrosion, adhesion characteristics, contact resistance, fluid flow, permeability, surface luster and reflectivity. The morphology and topography of the material surface directly affect these properties. The contact resistance between the bipolar plate and the gas diffusion layer (GDL) in a PEMFC (see Figure 2) constitute a significant portion of the overall fuel cell electrical resistance [3]. Properties such as thermal resistance, surface adhesion, and some tribological properties are impacted by roughness of the surfaces. This thermal and electrical contact resistance and the mass transfer resistance resulting in water holdup in bipolar plates are affected by the roughness of the plate surface. In addition, Lilavivat [4] suggests that there may be a significant drop in fluid pressure a reduced ability to remove water in bipolar plates because of plate roughness [4]

Surface roughness is a measure of the texture of a surface using statistical representations of the high frequency surface deviations (peaks and valleys) from the local mean surface height. When the variation between the peaks and valleys is large the surface is said to be rough, if they are small, the surface is smooth [2]. The peaks and valleys may be considered finely spaced surface asperities constituting a surface micro-relief. On the nano-scale, sub-roughness of a real surface is the result of distorted positioning of crystallographic planes, grain distribution in the material matrix, and the inclusions of micro and nano-oxide particles on the sheet surface.

The size of the asperities may vary from the length of the work piece to the atomic scale. The surface topography has a significant effect on the thermal, mechanical, and electrical contact of a material [5]. In reality when two surfaces are in contact with each other the contact takes place between asperities on each surface. The real contact "a-spot" is composed of clusters of nano-scale roughness [5] which are small cold weld regions providing the conducting path between contacting asperities on the two surfaces. In the case of two metals in contact, due to the presence of contaminants such as a thin layer of oxide, sulfides, and inorganic films on the surface of the metals, the asperities must penetrate the surface contaminants in order to make contact with the other metallic surface and establish

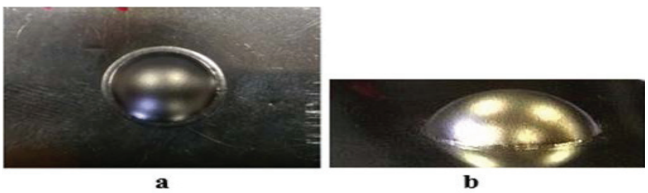

Figure 1: Bulge sample (a) top view (b) side view

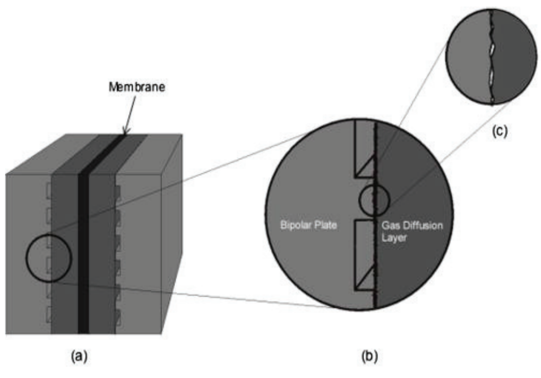

Figure 2: Schematic view of the contact interface between BPP and GDL [2].