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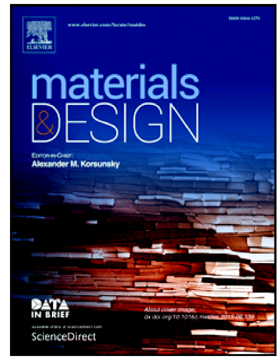

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Design, characterisation and performance evaluation of a Peltier-driven cryo-adhesive fixture for manufacturing operations

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Abstract

Workholding and fixturing is a critically important aspect of manufacturing that has direct implications for the quality of the manufactured component during processing as well as a direct impact on the cost of the component. The field of workholding is mature with numerous techniques employed, mostly using contact pressure, but also using magnetics and adhesives. Looking to nature for inspiration presents us with the use of ice as a mechanism for adhesion, referred to as cryo-adhesion. Cryo-adhesion offers some advantages over more traditional fixturing methods such as removing contact pressure and therefore reducing the dependence on the machining of complex, intricate bespoke fixtures. While the concept of ice adhesion is known, there is minimal research presented on the application of ice adhesion in manufacturing processes. This research reports on the development of a novel Peltier-based cryo-cooling fixture for workholding in manufacturing operations. The research provides insight into the main interactions that might be experienced in manufacturing type scenarios and presents findings on the cryo fixture's thermal and geometric characteristics, the use of the novel cryo fixture for holding various materials under tensile and shear loads, and a consideration of contact area and surface roughness on the cryo fixture performance.

Keywords

Ice adhesion; workholding; grasping; Peltier cooling; thermoelectric; manufacturing technology;

1. Background

The ability to hold and manipulate workpieces during manufacturing processes is critical to the production of high-quality product [1]. Traditionally, simple vices and other mechanical fixtures and clamps could be used to keep workpieces in place through contact pressure. For example, in recent decades milling, drilling, and grinding processes have been extended to progressively smaller and more delicate parts as the micro/precision manufacturing space has grown. Traditional clamping and fixturing principles based on contact pressure are often unsuitable for delicate manufacturing applications. This has led to the development of a variety of other clamping techniques and mechanisms, each with its unique set of benefits and drawbacks. A study of current manufacturing practices reveals that vacuum, magnetic, electrostatic, adhesive and nesting clamping techniques have already been adopted [2-4]. An alternative nature-inspired approach considers the use of ice as an adhesion mechanism. This research focusses on the development of an ice/cryo based fixture mechanism for manufacturing applications which is driven by Peltier cooling.

To date, the application of cryogenics in manufacturing has largely been focussed on cooling and stiffening workpieces during metal cutting processes as reported by Shokrani et al. [5] and Jawahir et al. [6]. Cryo adhesion has received little attention in this space. Cryo-adhesion is based on the formation of ice and it is known that when the temperature of a solid making contact with water falls below the freezing point, nuclei of solidified ice crystals begin to form as illustrated in Figure 1. Homogeneous nucleation occurs spontaneously throughout any water that has fallen below freezing. Heterogeneous nucleation, which occurs more frequently and rapidly, occurs against the cold solid surfaces and also against particles of impurities throughout below-freezing water [7]. The primary nucleation sites occur far from one another such that no significant interactions exist between them. Once lone ice crystals have formed in the water, they act as nucleation sites for further crystals to develop. Secondary nucleation is differentiated from later crystal growth by the fact that many ice crystals forming during this phase break free of the nucleation sites, and are left suspended in the water, possibly acting as further nucleation sites [8].

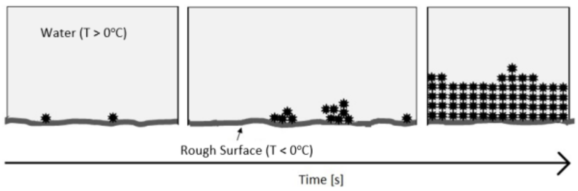

Figure 1: Primary and secondary nucleation, and bulk freezing, at the water-solid interface

The nucleation sites will grow in size and develop into multi-molecule grains. The grains will meet and join, forming ice crystals on a bulk scale. For the orientation described in Figure 1, a layer of ice will form from the bottom surface upwards.

From the literature it would appear that predicting the adhesive force of ice is difficult. It has long been suggested that a thin, amorphous, liquid-like layer can be assumed to exist between ice and the substrate it is bonded to. Indeed Faraday proposed the concept in 1859. The theory was developed by Weyl [9] and subsequently formalised by Jellinek [10, 11]. Many