Forming of titanium alloys, especially at room temperature, presents considerable difficulties due to a tendency to adhere to the tooling. The high frictional forces combined with the high yield strength and limited ductility of these materials at room temperature practically necessitates forming at elevated temperatures. There thus exists a need for developing new lubricant systems for the forming of titanium alloys at temperatures above 300°F. It is well established that friction contributes not only to the forming loads but also to work-piece surface quality and to tooling deterioration. In view of these effects the authors have been most active on the development of lubricants suitable for warm forming operations over the last three years.

The work reported upon gives an evaluation of several promising new lubricants, including solid lubricant mixes, using the Male-Cockroft ring deformation test. It is shown how solid lubricants can be blended to give an optimal friction coefficient under conditions of bulk plastic deformation.

The role these lubricants might have in actual forming operations, namely drawing and pressing, is also discussed and some important effects regarding press capacity, tooling and work piece finish enumerated.
Introduction

There has been significant interest in the technology of forming titanium alloy sheet over the last decade. Much of this interest has sprung from the demands of the aerospace industry for high strength lightweight aircraft components and indeed much of the metal forming technology has been developed in house by these organizations (1,2). Only in the last four or five years have academic institutions become interested in the type of problems associated with this technology. The present paper looks specifically at a research investigation of one aspect of this technology, the selection and development of lubrication systems.

The Current State of the Art in Forming Sheet Alloy

Many early attempts to produce pressings or drawn parts from alloys such as Ti-6Al-4V were thwarted somewhat abruptly. This is not surprising since, there are some special problems with the deformation of hexagonally close packed materials. These have been discussed elsewhere (3). Although titanium allows us a little more leeway in the availability of slip systems than more ideally close packed materials (3-5), the somewhat limited room temperature ductility of commercially available alloys such as Ti-6Al-4V in sheet forming processes involving certain biaxial stress states has been mentioned by several workers (6,7).

Because of this inherent difficulty, metal forming practitioners quickly recognized the advantages of warm or hot sheet forming of these alloys. Raising temperature in the systems involved, will clearly allow more possibilities for slip, whilst additionally it is found that springback problems are also minimized (1).

Another important aspect of hexagonally close packed material in sheet form is the presence of anisotropy in the product as received from the mill. Fortunately, the texturing effects exhibited in titanium alloy sheet are such that reduction in the thickness direction is minimized. However, pronounced ear formation occurs because of the planar anisotropy exhibited by the material. Cases have been reported where the ear formation and associated folding, together with the low ductility of the drawn material have resulted in failure of the product immediately after fabrication (7).

Finally, there has also been present the perennial difficulty of avoiding scoring and galling in these operations (6) problems to which titanium alloys have long known to be prone.

In attempting to overcome these difficulties simultaneously, the aerospace industries have looked extensively at elevated temperature forming using preheated dies. Frequently, temperatures of workpiece and die of 1000°F and above have been used. This move in