ON THE ROLE OF PLASTICITY LENGTH SCALE PARAMETERS IN MULTI-SCALE MODELING

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Abstract: This chapter presents a recent study of the effects of plasticity strain gradient length scale parameters on the plastic deformation of LIGA Ni MEMS structures plated from sulfamate baths. Micro-tensile experiments were explored in current study to evaluate the basic tensile properties for LIGA Ni MEMS structures at micron scale. The composite length scale parameter [1] was obtained from the micro-bend techniques, and the stretch gradient length scale parameter [1-4] was extracted from the nano-indentation experiments. A constitutive expression, which is an extension of the traditional J2 theory, was obtained for the LIGA Ni MEMS structures. This constitutive equation can be used for the further modeling of plasticity of LIGA Ni MEMS structures plated under similar conditions. The implications of plasticity length scale parameters are discussed for multi scale modeling between the micron- and nano-scales.

Key words: multi-scale models, MEMS, plasticity, nano-indentation, length scales

1. INTRODUCTION

In recent years, LIGA (an acronym of the German words “Lithographie, Galvanoformung, Abformung”) nickel Micro-Electro-Mechanical Systems (MEMS) structures have been developed for applications in larger and thicker micro-scale devices [5-8]. These include: accelerometers, micro-switches and micro-gears [5]. However, a basic understanding of the mechanical behavior of LIGA nickel MEMS structures is yet to be

developed. Furthermore, the possible effects of size-scale on plasticity in LIGA Ni MEMS structures are yet to be fully explored. Nevertheless, prior studies [1-4, 9-11] have showed that traditional continuum mechanics breaks down at micron and sub-micron scales which are dimensions of MEMS structures. Clearly, there is need for the development of a new governing constitutive equation that incorporates length scale parameters in the modeling of plastic flow conditions in LIGA Ni MEMS structures. Such an equation would facilitate the current effort to develop a multi-scale modeling framework between the micron- and nano-scales.

Furthermore, during the last three decades, there have been significant efforts to develop new plasticity theories that include the effects of plasticity length scale parameters [2-4, 9-10]. Two classes of plasticity theories have been developed. These include: (i) the phenomenological strain gradient plasticity theories proposed by Fleck and Hutchingson [2], and (ii) the mechanism-based strain gradient plasticity (MSG) theory developed by Gao, Huang and Nix [3, 9-10].

Most recently, micro-bend experiments have been conducted on LIGA Ni MEMS structures [11]. These show that plastic flow stresses in LIGA Ni structures are strongly affected by structural thicknesses in the range of between ~ 25 and 200 μm. Furthermore, nano-indentation experiments performed on LIGA Ni MEMS structures also showed length scale effects at sub-micron and nano scales. However, there have been no complete treatments of size effects in LIGA Ni MEMS structures. There is also a need for an accessible constitutive equation for the prediction of the plastic flow conditions at micron- and nano-scales.

This paper presents the results of a combined experimental and theoretical study of the effects of plasticity strain gradient length scale parameters on the plastic deformation of LIGA Ni MEMS structures plated from sulfamate baths. The structure of as-received LIGA Ni films is characterized using scanning electron microscopy, and orientation imaging microscopy. A constitutive expression, which is an extension of the traditional $J_2$ theory, was obtained for the LIGA Ni MEMS structures. This constitutive equation can be used for the further modeling of plasticity of LIGA Ni MEMS structures plated under similar conditions. This can also be shown to be a vital part of the current effort in developing multi-scale modeling framework.

2. MATERIALS

The LIGA Ni films that were used in this study were electrodeposited using sulfamate bath chemistry at Sandia National Laboratories, Livermore,
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Keywords

multi-scale models – MEMS – Plasticity – nano-indentation – length scales