# Fabrication of Micro Spur Gear in Nano Grained Al Alloy

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**Abstract**

*Manufacturing technologies of micro parts were studied in nano grained Al-1.5mass%Mg alloy. During compressive test at 300 ℃, the Al alloy showed stain softening phenomenon by grain boundary sliding regardless of strain rate. Micro spur gear with ten teeth (height of 200 μm and pitch of 250 μm) was fabricated with sound shape by micro forging. During micro forging, increase of applied stress induced by friction between material and die surface was effectively compensated by decrease of stress by strain softening behavior and as a result, flow stress increased only about 50 MPa more than that in compressive test*

**Keywords : micro forming, nano grained Al alloy, strain softening**

## 1. Introduction

MEMS industry is developing day by day and as the same time, requirement of structural parts miniaturized also increases. Plastic forming processes in manufacture of the tiny parts offer significant advantages in productivity and mass production. Then, material characteristics such as superplastic behavior act as a factor to affect quality and cost.

In this work, manufacturing technologies of micro parts by micro forging and pressing were studied in nano grained Al-1.5mass%Mg alloy and the effects of deformation behavior of material on plastic forming stress was also investigated.

## 2. Experimental and Results

Coarse Al-1.5mass%Mg (hereafter, referred to Al-1.5Mg) powders consisting of many nano grains were produced by mechanical alloying (MA) using elemental powders of commercial pure Al (99.5mass%) and Mg (99.9mass%). After MA, the powders were hot pressed for 40 min at 500°C under pressure of 50MPa in vacuum. The material hot pressed were machined to rectangular type specimens with dimension of 4mm×4mm×5mm (Width×Depth ×Height) or cylindrical those of ϕ0.8×1mm by electrical discharge machining method and then, surfaces of them were polished out to remove an effect of EDM.

Compressive tests were conducted to true strain of about 1.0 at 300°C with initial strain rates from $1\times10^{-1}\ s^{-1}$ to $1\times10^{-4}\ s^{-1}$. To reduce friction between dies and specimen, $MoS_2$ powders were sprayed on surfaces of dies. From data of load and displacement obtained during compressive test, true stress and true strain were calculated assuming that barreling does not occur (actually, barreling was suppressed effectively to true strain of 0.4).

After hot pressing, analyzed composition is almost consistent with nominal one. Relative density was measured to 99.2% and this indicates that it is possible to exclude an effect of porosity in compressive tests and micro forming. Average grain size was measured to about 100 nm and in selected area diffraction (SAD) pattern, clear rings were observed owing to fine grains.

Compressive deformation behaviors in nanocrystalline Al-1.5Mg alloy was investigated at 300°C. In load-displacement curves, a phenomenon that load suddenly drops after yielding took place at all strain rates except $1\times10^{-1}\ s^{-1}$. Also, it is noted that after occurrence of load drop, region where load is constantly sustained (hereafter referred to plateau) came out, especially at strain rate of $1\times10^{-3}\ s^{-1}$. In true stress-strain curves of Fig. 1, it can be seen that conspicuous strain softening occurred due to load drop after yielding and this strain softening is reported to occur due to grain boundary sliding[1,2].

Micro pressing and micro forging involving extrusion were performed for fabrication of micro spur gear with size of 1.2mm consisting of ten teeth. The forming was carried out at initial strain rate of 1x10-3 $s^{-1}$ and surfaces were lubricated by $MoS_2$ powders. Spur gear (1.2 mm in diameter) aimed in this work consists of ten teeth with height of 200 μm and pitch of 250 μm, and micro forging involving extrusion into pin hole were carried out using dies with shape of the micro gear. In case of micro forging involving extrusion into pin hole, as shown in Fig. 2, load-displacement curve is divided to two areas: one is an area of spur gear forming by forging and the other that of pin forming by extrusion. In stress-strain curve on gear forming,

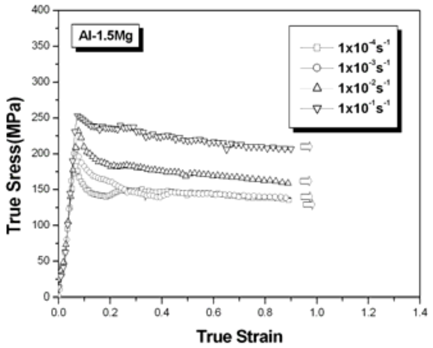


**Fig. 1. Load-displacement and true stress-strain curves of nanocrystalline Al-1.5Mg alloy compressive tested at 300°C (The arrows mean continuous deformation without fracture).**

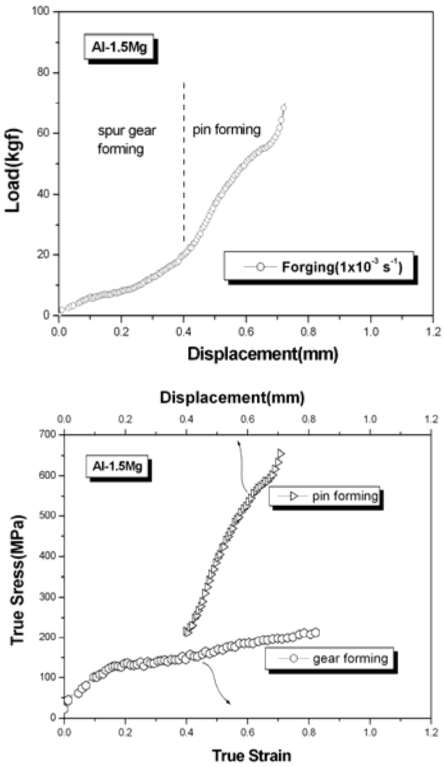


**Fig. 2. Load-displacement and stress-strain/displacement curves in micro forging. The stress-strain curve is related to micro gear forming and the stress-displacement curve to pin forming by extrusion.**

flow stress increased only about 50 MPa more than that in compressive test. This seems to result from softening behavior of sample to decrease flow stress, implying that strain softening phenomenon is very useful to compensate increase of friction force in micro forging process. Fig. 3 (a) shows sound micro spur gear by forging (material flow occurred slightly though clearance between upper punch and die).

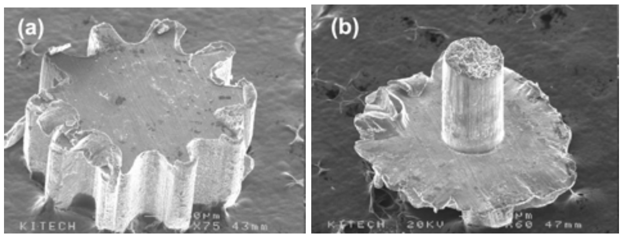


**Fig. 3. SEM microphotographs of micro spur gears formed by micro forging. (a) and (b) show micro spur gear and pin by micro forging involving extrusion into pin hole, respectively.**

On the other hand, in direct extrusion process, the stress (or pressure) progressively decreases with decreasing length of sample in die[3]. However, as can be seen in stress-displacement curve on pin forming of Fig. 2, stress increases rapidly though length of sample decreases. Also, comparing to the stress-strain curve of micro gear forging, the increase of stress is very large. These results may be explained through the softening behaviors in Fig. 1. The softening occurs shapely in early stage of deformation and then, the degree of softening gradually decreases. Thus, micro extrusion process following micro forging in this work would be not received largely a favor of softening behavior. Fig. 3 (b) shows SEM microphotograph of micro pin (during fabrication of micro pin, some of material was squeezed out between lower punch and die).

## 3. Summary

Using strain softening phenomenon in nanocrystalline Al-1.5Mg alloy, micro spur gear with size of 1.2mm consisting of ten teeth was fabricated with sound shape by micro forging. During micro forging, increase of applied stress due to friction between material and die surface was compensated effectively by decrease of flow stress by strain softening.

## 4. References

(1 line spacing)

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