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Effects of Grain Size on Surface Roughness of Thin Pure Cooper Sheets in Metal Micro Forming

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Abstract:
Size effect is a superior occurrence in the micro scale forming. When the distortion or deformation happened on micro scale, the presences of grain size and geometry of the selected material start playing an important role on the material deformation behavior. Here in this study, the influence of size effects on surface roughness is inspected. To investigate the impact of size the workpiece geometry and grain size both are considered in the form of t/d relation (t= material thickness, d = average grain size). In this exploration, the micro tensile tests was carried out on the copper foil (t = 50 μm), where to attain different grain sizes, the foil were annealed for different time. The surface roughness of all tensile tested copper samples is tested on the 3D laser-scanning microscope. The identified analysis provides a basis for further vital exploration to understand the influence of size effects in metal micro forming.

Keywords: *Size effects, Copper samples, Tensile test, Micro-forming.*

I. INTRODUCTION

In the recent years, the micro metallic parts have been attained more attention due to their wide applications and superior characteristics [1]. The metal micro forming is an excellent deformation process, which is mostly used to manufacture the submillimeter range metallic parts [7]. Metal micro forming is a noticeable field where size effects play a major role. In metal micro forming, all the process problems and material behavior problems are only emphasized with regarding the size effects [1, 10]. The relationships between the dimensions, microstructure, and surface geometry in treated workpieces as well as in tools are different in macro and micro-scale forming, which caused the formation of 'size effect' phenomenon [1,9]. Therefore, the study of deformation behavior characteristics of different materials foils is very important to understand the influence of size effects in metal micro forming.

In metal micro forming technology, a great deal of research on size effects on material deformation behaviours of thin films have been studied extensively in the previous researches [5], but the micro-scales investigation for thin films are typically at least. In the metal micro forming, the surface roughness is mainly initiated by non-uniform deformation of metal foils. Moreover, the incrementation in surface roughness is one of the main factor affecting the ductile fracture that is only occurs during plastic deformation of metal foils. Thus, it becomes weighty to clarify the mechanism of surface roughness in metal micro forming. The features of a single grain involved in the deformed region of a material start playing a major part in the material deformation behaviors, when the deformation process rules down to micro scale, [10]. In this study, the influence of different grain sizes on the surface roughness of very thin copper sheets have been investigated by conducting micro tensile tests

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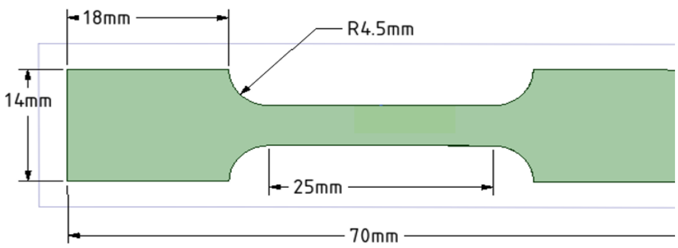
II. MATERIAL

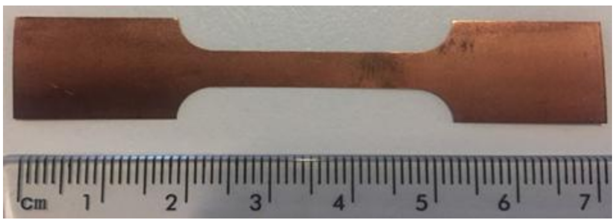
Nonferrous metals are broadly used in electrical devices in terms of micro parts due to their high electrical conductivity and good ductility. The outstanding wear resistance and bearing properties enhance the applications of nonferrous metals. The most commonly used wrought forms are strips, rods, and tubes. In this study, a pure copper (99.9 %) foil is selected as the investigational material. The schematic and actual copper tensile sample is shown in Fig.1 (a-b).

III. HEAT TREATMENT AND POLISHING

To obtain different average grain sizes in the selected material and to achieve different thickness to grain size effect ratios, annealing process was carried out. The micro tensile samples were annealed in a well-sealed vacuum tube annealing furnace (Fig.2 (a)). Because the samples are very small, besides vacuum condition during heat treatment, the Ar air protection was also adopted to avoid oxidation. After annealing, samples for micro tensile test were etched using a solution of 5ml saturated aqueous sodium thiosulfate, 45mL water, 20g potassium metabisulfite for 10 seconds.



(a)



(b)

Fig.1. (a) Diagram of micro tensile samples
(b) Real copper specimen

The most difficult job was to get a high diamond finish on copper samples for determining the average grain size. The normal size Alpha aluminium powder (0.5 and 0.3 microns) used to polish the copper samples. To achieve a good shine in soft cooper material the Alpha aluminium powder was constantly rubbed on samples after grinding.

Table.1. Sample preparation procedure for microstructural analysis

Procedure	Surface	Solution
Grinding (2 min)	9 µm Largo cloth	Water
Polishing (1 min)	3 µm Mol cloth	Alpha or Gamma aluminium powder (0.5 microns)
Polishing (20 sec)	OP-chem	Alpha aluminium powder (0.3 microns)

All the samples were mounted on grinder and polish machine, as shown in Fig.2 (b). The grinding and polishing procedures for metallography are presented in Table.1.

(a)

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(b)
Fig.2. (a) Vacuum tube annealing furnace, (b) Grinder and polish machine

IV. 3D LASER SCANNING MICROSCOPE

An electric stage, and a large area of the strained foil surface can be observed by using different lens to enlarging the pictures automatically. To measure the average grain size after polishing, the average grain intercept method (AGI) is used. In AGI technique, different line segments are marked on the microstructure pictures and then counting the number of times each line segment intersects a grain and quantify the grain size in a given material [12].

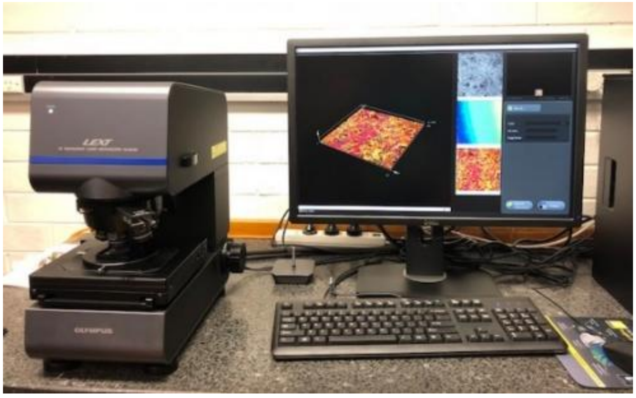
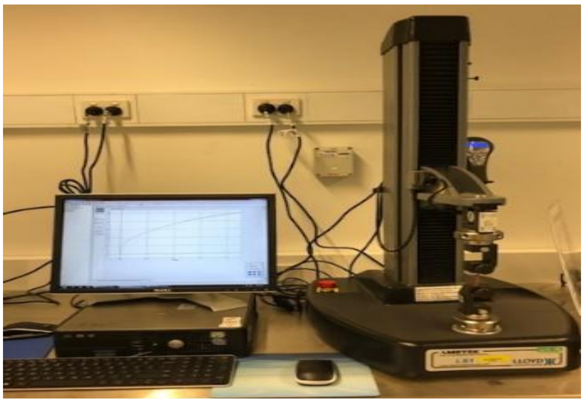


Fig.3. 3-D laser scanning microscope

This 3D laser confocal microscope is also used to the precisely measures shape and surface roughness at the submicron level. All the microstructure and grain size of the prepared specimens before the tensile test are in shown in Table.2.

V. EFFECT OF T/D ON TENSILE TEST AND SURFACE ROUGHNESS

The impact of grain size comparative to the sample thickness becomes very important, specifically when the sample is actually thin, and then the t/d effect is analyzed with flow curves. To carry out the uniaxial micro tensile test on materials with different grain size effect ratios, a set of METEX universal tensile testing machine with a maximum capacity of 1KN (as shown in Figure.4 (a)) is used. The true stress-strain curves of the copper samples with different grain sizes are shown in Fig.4 (b). The true stress-strain graph represents the required stress to origin the further plastic flow in the material. In the previous studies, the selected ratios are only used to investigate the flow stress in thin foils not for the surface roughness. However, in this work all, these three ratios are studied to understand the occurrence of the surface roughness and the crystal orientation between the grains that effects it most. Therefore, in the three nominated different ratios of t/d the different surface texture images were attained with the help of 3D laser microscope. After the tensile testing the height profile and surface texture are observed (as shown in the following Fig.5 and Fig.6, respectively). It is observed that in the deformed samples the surface roughness is amplified expressively with the reduction of t/d, because the surface grains are less constrained and easier to deform on the free surface with small ratio of t/d. Further, Fig.5 (a-c) shows the height profiles of tensile tested samples all the copper samples are tested on the 3D laser-scanning microscope. From Fig.7, it can be clearly observed that the surface roughness increases with the decrease of t/d ratio. Because, in t/d<1 the average grain size is greater than sample thickness, which means the grains involved in the tensile samples are incomplete. Consequently, due to the lack of grain boundaries it becomes very easy to initiate the surface irregularities.



(a)

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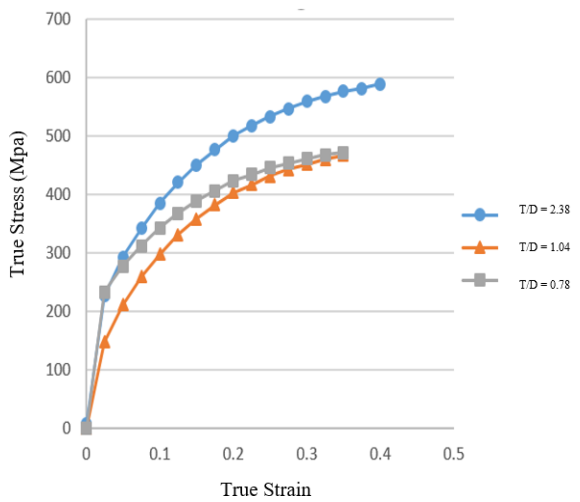
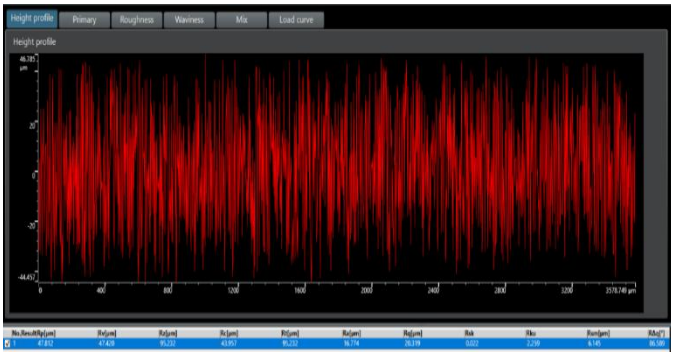


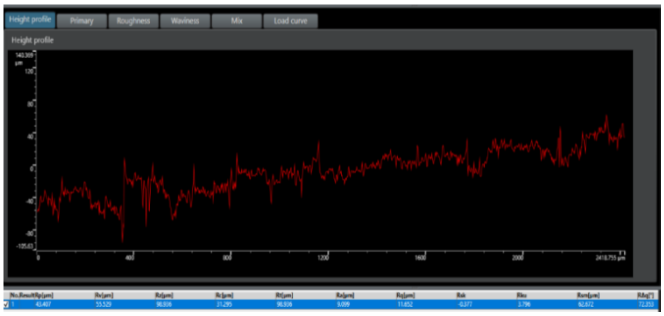
(b)

Fig.4. (a) METEX universal testing machine

(b) True stress-strain curves



(a)



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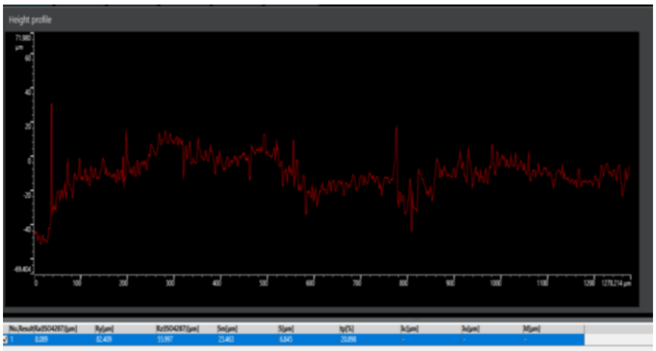


(c)

Fig.5. Hight profiles of (a) t/d = 0.78
(b) t/d = 1.04
(c) t/d = 2.38

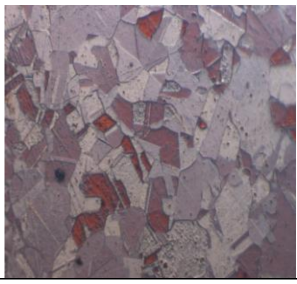
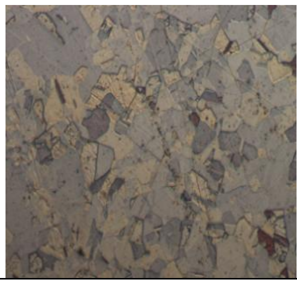
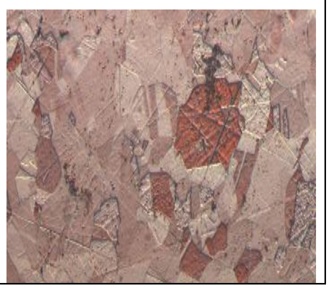
	Sample 1	**Sample 2**	**Sample 3**
Material	Copper	Copper	Copper
Temperature	600	600	600
Time	10 min	20 min	30 min
Thickness	50 µm	50 µm	50 µm
Average grain size	21 µm	48 µm	56 µm
t/d	2.38	1.04	0.78
Microstructure			

Table.2. Microstructure and grain size of the specimen

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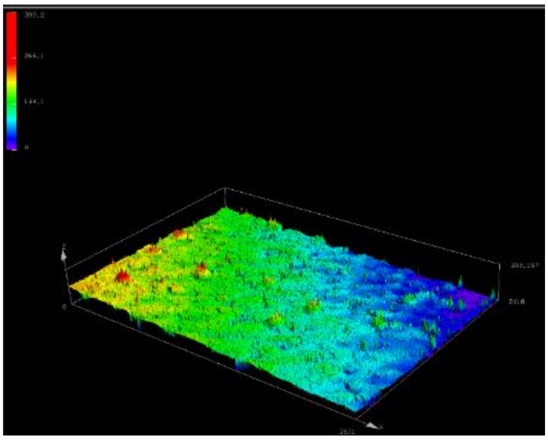
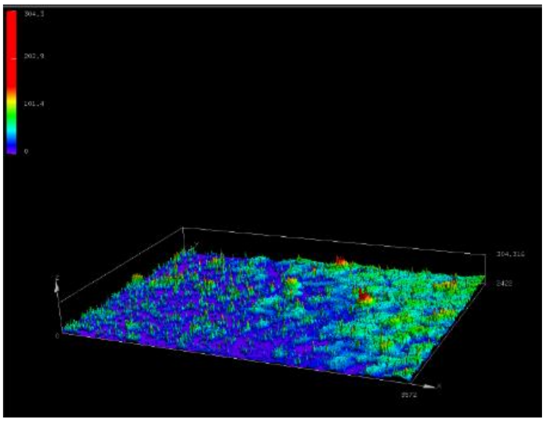
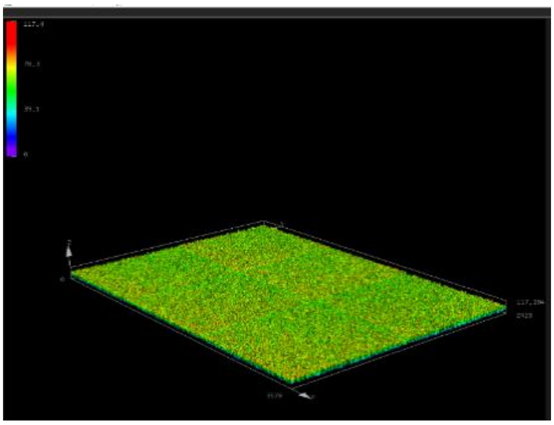


(a)



(b)



(c)

Fig.6. 3D Surface texture of (a) t/d = 0.78, (b) t/d = 1.04, (c) t/d = 2.38

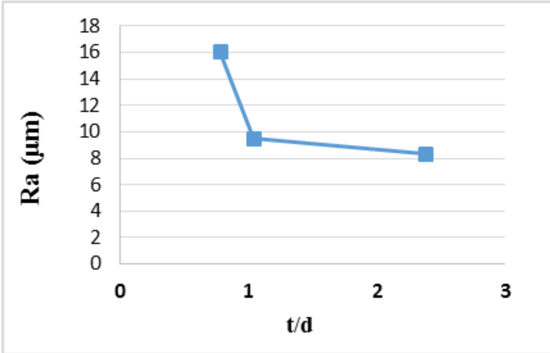


Fig.7. Surface roughness vs T/D

VI. CONCLUSION

In this article, the influence of the size effects on selected material surface roughness are investigated. To confirm the effect of T/D ratios, the surface roughness analysis has been conducted with tensile tests for pure copper foils. From this study, it is found that in deformed samples the surface roughness is expressively increased with the decline in T/D ratio. In other words, we can say that the surface roughness increases with the increase of grain size. The reported results from this study also help to define the hardening behaviour of grains in polycrystalline material. This investigation provide vital evidence to the effect of surface roughening on the ductile fracture behaviour.

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