A review on micro-extruded microstructure from ultra-fine grained and as cast

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Abstract

As per industrial requirement and application of micro part in micro-manufacturing process, grain size is an important factor. Studying microstructure revels the size of grain, based on this different types of grains are defined. Deformation behavior in micro extrusion process of coarse grain (CG) material is inconsistent when scale changes from macro level to micro level known as size effect. Hence refinement of grain is done through different approaches by severe plastic deformation (SPD). Such Ultra fine grain (UFG) material is useful for micro extrusion process as its property are enhanced as compared to CG material obtained from as cast. Equal channel angular pressing (ECAP) is one of the best techniques of SPD to produce UFG material with shear deformation. Refinement of grain is done through number of passes using ECAP which changes the size of grain up to nanometer level. Beyond certain number of passes grain size do not alter and leads surface defects. As cast micro extruded product seems to be inhomogeneous and having wide deviation of physical and mechanical property all along its axis. Whereas ECAP based micro extruded product is homogenous and having uniform physical and mechanical property all along its axis. The advantages of ECAP based micro extrusion is that grain size and direction of grain can be altered based on requirements and type of application.

Keywords: Micro-extrusion, CG, UFG, Changed property.

1. Introduction

M Geiger et al. (2001) suggested that any two dimensions of a fabricated parts lies below 1mm range is known as micro part. Present technology moving towards the micro technology. Interest of micro technology is due to miniaturization like consumer electronic product, phone, computer, micro tool, micro robot part etc. with good mechanical and electrical property. Industry work to maintain the quality of micro product as per recruitment by different processes like micro-machining, micro-forming, micro-moulding, advanced lithographic etc. The properties and microstructure in the same micro parts are different with different micro manufacturing process as described above. W.L. Chan et al. (2011) have studied the forecasting of deformation behavior is not valid when scale go down from macro to micro level. F Vollertsen (2008) has categories the size effect into three categories known as density effect, shape effect and microstructure. They also suggested that microstructure changes with change in temperature because of frictional effect between die and material hence frictional factor is nullified with help of lubricating oil like MoS_2, cutting oil, or grease. U Engel et al. (2001&2002) developed flow stress relation as a function of grain size, part dimension and grain ratio (ratio of average grain size before extrusion to average grain size after extrusion). V.M. Segal (1995) and (2008); R Z Valiev et al. (2000); A Rosochowski (2005) and Z Horita (2005) and A. Azushima et al. (2008) explain that SPD is the technique to change CG into UFG by various processes, some of them are ECAP, Accumulative roll bending(ARB), High pressure torsion(HPT), sever torsion straining(STS), Cyclic extrusion compression(CEC) are the technique to produced ultra-fine grain. ECAP is most promising technique to produced ultra-fine grain by SPD with shear phenomena with introducing large plastic strain without changing the initial dimension of sample. By SPD grain structure changes from micrometer to nanometer range with increasing mechanical property. ECAP produces the part with high strength to weight ratio, long life and good mechanical property as compared to CG material.

Following sections discusses the properties enhancement due to severe plastic deformation, microstructure of course grain and ultra fine grain and its deformation behaviour and its application through micro extrusion process

2. As cast microstructure

As cast is the pouring of molten metal into a mould cavity having different shape and size. Normally Grain formed by this process is non-homogeneous, non-uniform distribution over the surface of casted product. Grain size depend upon the Time-Temperature-Transformation (TTT) diagram and hence control of grain size depend upon the type of constituents, percentage of constituents, its solidification points, time of solidification, gasification (removing impurities from molten metal in slag form), pouring pattern and pouring time. Microstructure formed through as cast lies in the range of sub-millimeter to sub-micrometer.

E Paul Degarmo et al. (2003) have studied Solidified Grain structure at low temperature condition posses with three different region are known as chill region, columnar region, and equiaxed region as shown in fig. 1.

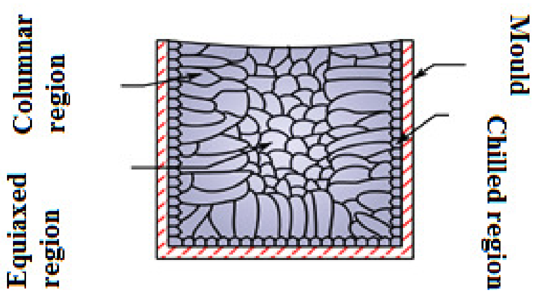

Fig. 1 Formation of microstructure
(E Paul Degarmo et al. 2003)**.**

Chill region in nucleation shape is near part of mould cylinder where more heat transfer to the surrounding. Columnar region is anisotropic region which is long and having identical property in all direction, where as equiaxed region is isotropic in nature (uniform in all orientation).

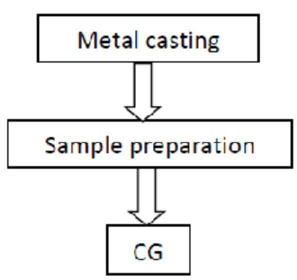

Fig 2. Flow chart for CG microstructure preparation

3. UFG microstructure

UFG microstructure is the refine grain structure from as cast grain with various type of technology. V M Segal (1995 and 2002) has studied the grain structure of material through SPD based ECAP technique. ECAP based technique work on the principle of shear deformation imposing high strain rate without any change in sample initial dimension. ECAP channel is bent an abrupt angle (Φ-channel angle and ψ-corner angle) in a die as shown in fig. 3. Sample is pressed through the inlet channel by plunger and ECAPed sample comes out from outlet channel by shearing at corner angle. Shearing at corner angle remove the porosity, dislocation and casting defect, which enable to generate more number of grains. They suggested that grain refinement is possible for a limited number of passes beyond which crack will propagate over the surface. During pressing of sample back pressure is required to prevent it from surface crack. Similarly lubricating oil is required to prevent it from surface crack as well as recrystalisation which leads to refinement of grain. After SPD, surface grain size decreases and hence number of grain per unit surface area increases. Thus UFG contain more than number of surface grain as compared to CG. Normally refinement of grain is done at angle of die $\Phi = 90^0$ and $\psi = 0^0$ as tested through experiments. Sunal Ahmet Parasiz et al. (2007) have used ECAP based technique to obtain UFG in which multi directional grain are altered to only one direction with homogeneous grain distribution as compared to CG.

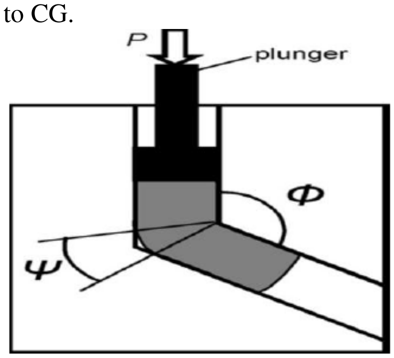

Fig. 3 Die drawing for Schematic representation of ECAP process (V M Segal 1995)**.**

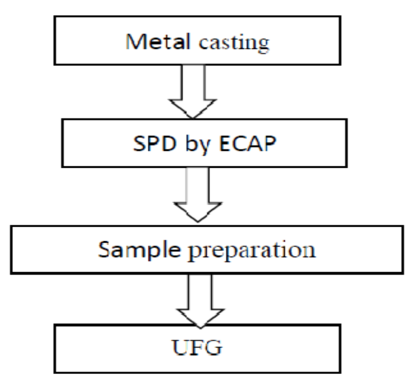

Fig. 4 Flow chart for UFG microstructure preparation

4. Effect of grain size

From studies of grain structure on same scale, number of grain in UFG sample is more than CG sample because of SPD shearing principle.

Xinmin Lai et al. (2008) during study on material behavior modeling in micro/meso scale forming have observed two different size effect of the grain, one is grain size effect fig. 5(a) and another is feature size effect or scale effect Fig. 5(b). They defined the dimension of the grain as D=CG and d=UFG on same scale. They defined grain size effect when size of grain on same scale is D to d or vice-versa. When size of scale is reduced from conventional to micro level keeping same grain size is known as feature size effect/Scale effect. W.L. Chan et al. (2011) have predicted inconsistent deformation behavior when scale changes from macro to micro level known as size effect.

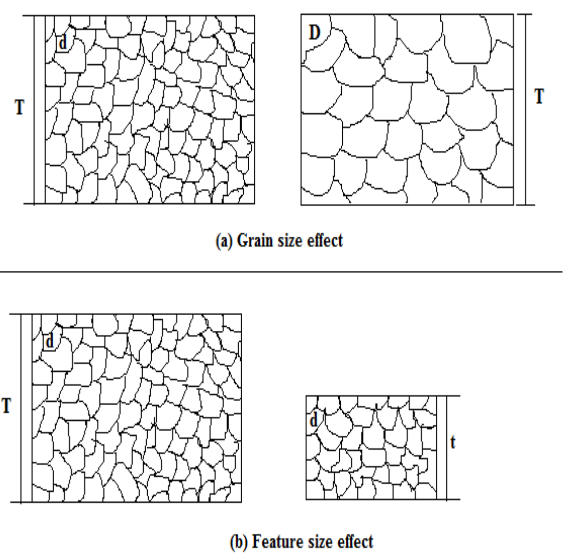

Fig. 5 (a)Grain size effects and (b)feature size effects with the decreasing of scale (Xinmin Lai et al. 2008)**.**

Size effect changes the flow stress of material in micro extrusion. E.O. Hall (1951) and N.J. Petch (1953) have developed relation showing that effect of grain size with yield stress as given in eq^n(1).

$$\sigma = \sigma_o + K\sqrt{D}\,, \qquad (1)$$

where σ = yield stress, σ_o = friction stress, k = Hall-petch coefficient, D = diameter of grain. F Vollertsen (2008) have categories size effect into three categories known as density size effect, shape size effect, and microstructure effect as shown in fig. 6 and table 1.

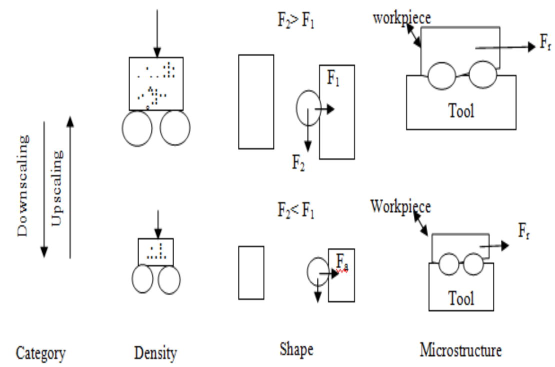

Fig. 6 categorized Three subcategories of size effects (F Vollertsen 2008).

Table 1(F Vollertsen 2008)

Categories	Subcategories	Effect
Density	Interface area density	Scatter in flow stress
	Line length density	Yield Strength of whisker
	Point defect density	Changing failure strength of brittle material
Shape	Shape balance	Adhesion to griper in force relation
	Shape sum	flow stress increases when grain lies on surface
microstructure	Characteristic length	Hardness decreases with increasing depth of indenation
	Microgeometry	Friction increases with decreasing grain size
	Secondary artefact	Flow stress decrease with increasing grain size, if grain size greater than sheet thickness

5. Property because of CG and UFG in micro-extrusion

5.1 Change in microstructure

S. Geißdörfer et al. (2008) have studied visibility and structure of as cast CG copper sample and 8 passed ECAPed UFG copper sample as shown in Fig. 7 (a) & (b). They suggested that beyond certain pass visibility and refinement of the grain is not feasible.

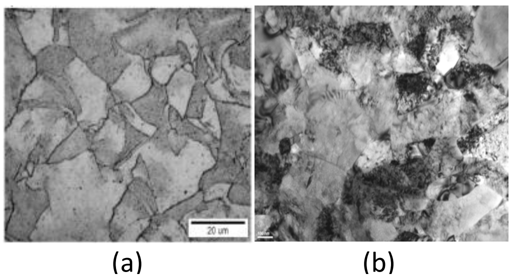

Fig. 7 structure of (a)CG and (b)UFG
(S. Geißdörfer et al. 2008).

5.2 Flow stress

Flow stress depends on number of grain present on outer surface and in inner volume of sample. Xinmin Lai et al. (2008) studied that decreasing in the size of specimen increases the total number of outer surface grain which leads to decrease in flow stress as given eq^n 2.

$$\sigma = \frac{N_s\sigma_s + N_i\sigma_i}{N}, \quad \text{where } N = N_s + N_i \qquad (2)$$

Where σ is material flow stress, N = total number of grain, N_s =Number of surface grain, N_i = Number of inner volume grain, σ_s = Flow stress of surface grain, σ_i = Flow stress of inner volume grain.
U Engel et al. (2001) studied the flow stress vs surface grain through experiment. They observed that flow stress decreases with increase in surface grain as shown in fig. 8.

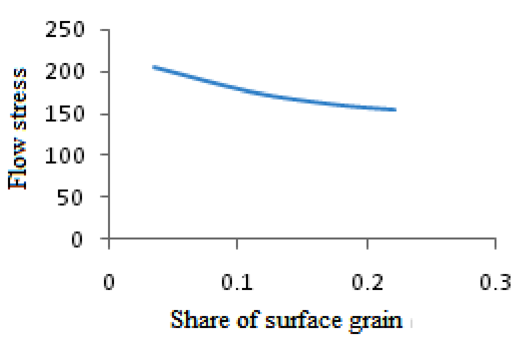

Fig. 8 Flow stress with share of surface grain
(U Engel et al. 2001).

5.3 Stress-strain curve

SPD processes impose a very high strain rate in each passes thus minimizing the dislocation between the grains which leads to increase in the number of grain. W.L. Chan et al. (2011) in their study suggested that load during deformation of micro extrusion depend upon number of grain in sample. If number of grain is more than friction will be high which required maximum load to deform the material. They have observed the true stress vs true strain for UFG and CG sample as shown in fig. 9.

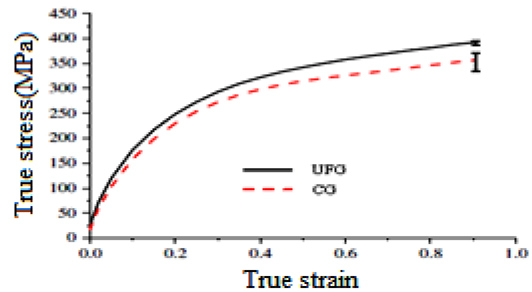

Fig. 9 Flow stress-strain curve
(W.L. Chan et al. 2011).

5.4 Flow of sample

Sunal Ahmet Parasız et al. (2011) in their study of micro extrusion of pin have observed the larger curvature of pin for CG sample as compared to UFG sample as shown in fig. 10. They concluded that curvature depend upon size of grains as well as degree of freedom (DOF) in its cross sectional area. Larger is the size of grain more is the curvature of the pin. Large is the DOF more is the curvature of pin. In UFG size of the grain are smaller as compared to CG thus having less pin curvature. Similarly in UFG DOF is restricted by larger number of grain as compared to CG thus having less pin curvature.

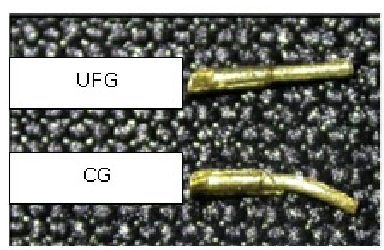

Fig. 10 Flow pattern of CG and UFG sample
(Sunal Ahmet Parasız et al. 2011).

5.5 Strength

F. Vollertsen et al. (2009) observed that grain size decreases due to miniaturization as a result of which strength of material increases as shown in fig. 11.

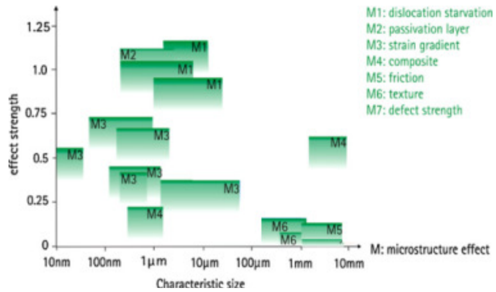

Fig. 11 Strength of material with microstructure size (F. Vollertsen et al. 2009)**.**

5.6 Applied force

Andrzej Rosochowski et al. (2007) have found experimentally that required force in micro extrusion of UFG material is higher as compared to CG material for a fixed length of deformation as shown in fig. 12.

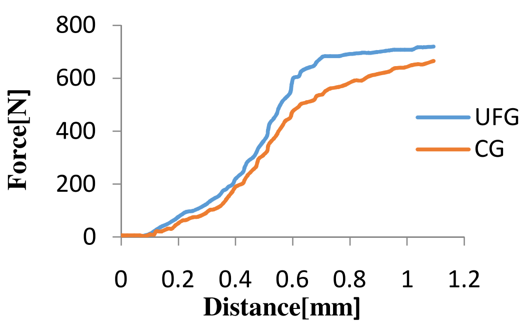

Fig. 12 Force variation in CG and UFG material (Andrzej Rosochowski et al. 2007)**.**

5.7 Hardness

Sunal Ahmet Parasız et al. (2011) have observed that average micro hardness of UFG material is more than the CG material as shown in fig. 13(a). They also observed that average micro hardness of material altered after micro extrusion as shown in fig. (b).

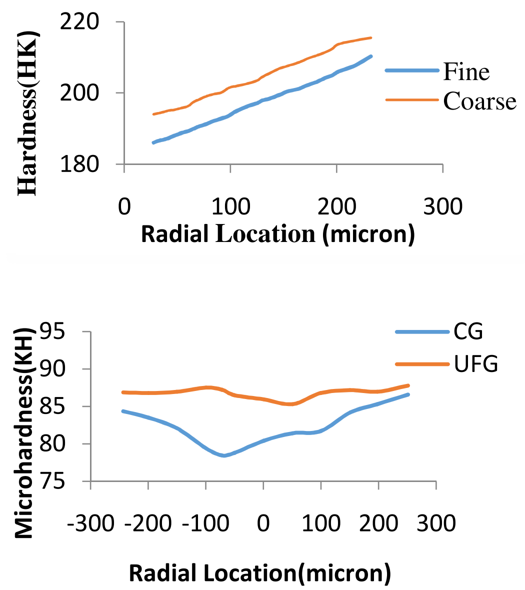

Fig. 13 micro hardness of CG and UFG (a) before and (b) after extrusion (Sunal Ahmet Parasız et al. 2011)**.**

FK Chen et al. (2006) have developed a relation between flow stress(K_f) and Hardness(H) as given by eq^n 3

$$K_f = \frac{H}{3} \qquad (3)$$

5.8 Wear property

Wear property of material is depends on number of grain present in its contact surface. More the number of grain means more is the wear life. Grain in UFG sample is more than CG.

6. Application

Based on dimension micro extruded part used in designing of micro-robot part, electronic micro part, medical equipment where high strength is to weight ratio is required, while based on their microstructure vibration absorber, wear resistant etc. can be designed.

7. Conclusion

From the present literature review following conclusions are derived

- Forecasting of deformation behavior is not valid when scale go down from macro to micro level
- Microstructure changes with change in temperature because of frictional effect during micro extrusion, hence lubricating oil are provided to nullify the friction effect.

- ECAP based micro extrusion is most promising technique to produced ultra-fine grain with high strength to weight ratio, long life and good mechanical property
- Better grain refinement is obtained at angle of die channel angle (Φ) = 90^0 and corner angle (ψ) =0^0
- Grain refinement is possible for a limited number of passes beyond which crack will propagate over the surface.
- Flow stress decreases with increase in surface grain
- Larger is the size of grain more is the curvature of the micro extruded pin.
- Strength of material increases due to decrease in grain size
- Average micro hardness of UFG material is more than the CG material. But its hardness altered after micro extrusion

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