Designing of an Equipment to Nanostructuring by multi-path Shearing

A. Epureanu, V. Marinescu, V. Tabacaru,
O. Naidim, F. Marin

University “Dunarea de Jos” of Galati, Mechanical Engineering Faculty, 111 Domneasca street, 800201, Galati, Romania

ABSTRACT

This paper presents the conception, design and manufacturing of a new equipment for nanostructuring the metals – aluminium alloy in the present case- by multi-directional shearing process. Changing the path of the deformation lead to an accumulative strain that cause the shear of the grains. By controlling the path of the deformation with the possibility to change the direction of the deformation, the accumulated strain increases up to 60% so that the that the grain size produced are almost 100 nm. The equipment that allows implementation of the proposed method is presented with details concerning functioning and possibilities to be industrial scale implemented.

Keywords: *bulk nanostructured materials, multidirectional shearing, designing of an equipment*

1. Introduction

Recent reserches have shown that metals with very fine grain sizes (< 10 µm) have higher strain rate rate sensitivity and greater elongation to failure at elevated temperature, exhibiting superplastic behaviour.
Severe plastic deformation (SPD) processes are a new technological steps in achieving nanostructuring of any metal that appears recent as an important target due to the size of the grains obtained in the parts- ultrafine grained (UFG) [1-4]. This size of the grains gives the metals desired combination of mechanical behaviour such high strength and good ductility. Superplasticity is one of the main mechanical characteristic of the nanocristaline structures which means that a material can elongate beyond 100% of its original size. In the last years, the most developed severe plastic deformation processes are Equal channel angular extrusion or pressing (ECAE/P), high pressure torsion (HPT), accumulative roll bonding(ARB) and multi-axial compression/forging (MAC/F) all aim to keep the starting and finishing work piece shapes the same. Among the processes, some like ECAE/P, MAC/F, and HPT introduce severe plastic deformation on bulk materials, while others like ARB, RCS, and Con-shear work on sheet materials [Rosochowski, 2005, Valiev, 2000]. The above-presented SPD processes produce UFG.
By analysing the presented nanostructured processes and the corresponding level of grain size obtained it results the following:
1. The average grain size obtained within a SPD process varies between 300 nm (HE) till 60 nm (HPT). This shows that the stress state during the nanostructuring process influences the grain size. This lead to the conclusion that a controlled patern of the deformation improves the uniformity of the grain size [7-8].
2. The direction of the stress in most of the SPD processes is along the deformation direction, that limits the deformation rate applied to the material (the amount of shear is limited to the cumlative value of the monotonic shear and Bauschinger shear [9-12]).
3. The deformation paterns are the same and a relation between the mechanical behaviour of the material and the shape of the pattern doesn’t exists. Starting from this observations, the paper presents a new schema for a nanostructuring process. To produce long pieces of processed material, one simply needs to take a longer starting stock. When a metal

billet is used, due to elastic deformation and the Poisson effect, there is a lateral expansion of the billet in the entrance channel, and very high frictional forces develop between the work-piece and the channel walls. The force required to press a billet through the die increases very rapidly with the length of the billet. Correspondingly, there is also a large increase in stresses experienced by the die. To overcome this inconvenient, a new method of nanostructuring based on multi-directional shearing is proposed.

2. Basic principles in designing of a new method of bulk nanostructuring

Nanostructuring method is based on nanostructuring by controlled multidirectional shearing and consists in compression of blank 1 by forces F_1 and F_2, in order to impose an extreme stress, followed by plastic deformation (shearing) of the blank 1, according to figure 1, where the part of blank 1 which is included in element 29 vs. the part of the blank which is included in element 28 and in a perpendicular plan on the centre line of the blank, describes a course ***T*** of which the shape and the rate assure an ultrafine fragmentation of the crystalline grains. The course shape can be programmed. For example, in the case presented in fig. 1, the course (deformation path) is O-t_1-t_2-t_3-t_4-t_5....O. Further more, by displacement ***s*** of the blank, in axial direction, the deformation area is displaced along the blank centre line, and the deformation path is periodically changing or not.

Hereby, in two nearby cross sections, the deformation path obtained, can be the same or different. The distance between two nearby sections represents the nanostructuring step ***p*** and can be appropriate controlled. According to the nanostructuring properties of the material, the optimal values of process parameters, forces ***F1*** and ***F2***, advance of the tool ***s***, course ***T*** and the course crossing rate are programmed at the optimal values so that the entire nanostructuring capacity by plastic deformation can be used. The course ***T*** is going to and leaves from the origin of X and Y axis. Crossing the entire course T, represents one cycle of nanostructuring. Using an interface, can be programmed the entire work cycle of the machine according to the necessity.

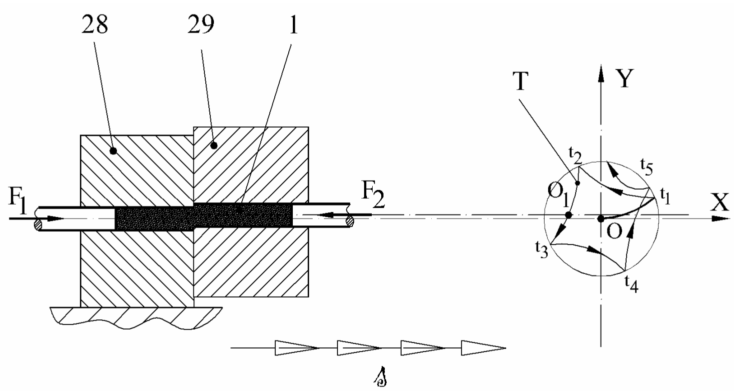

Figure 1 Basic principle of the multi-directional shear manufacturing process

Moreover, through the workmaterial feet rate s, along with the axial direction, the deformation area is moved along the whole workmaterial, even the pattern of the deformation is not changed. Thus, in two neibourgh transversal cross-sections, the carried out pattern could be the same. The distance between the two cross-sections represents step p of nanostructuring and it could be set up. The optimum values of the process parameters are chosen, that measn set up of the forces F1 and F2, feed rate s, pattern T and the speed of the active die movement. The patern starts from O and return to the origin after a complet cycle of the nanostructuring (T).

The workmaterial 1 undergo to the nanostructuring is in contact with 2', 2" ande 18' şi 18", as well as the parts 9, 12 şi 14. The pairs of the parts 18' - 18" are fixing with the workmaterial 15, following the oil pressure pa that allow the contact with the workmaterial. The plunjers 22' and 22" are closed each other and compress the spring in the same time 30. When the pressure decreases, the spring 30 is extended plunjers 22' and 22" in contact with 23' şi 23". Similarly, the pressure pb of the oil from the room b, parts 2' and 2" are fixing the workmaterial and the piston 5.

Along the axis, the parts 2' and 2" are fixed by the piston 5 by means of screw 3. Similarly, the pairs 18' and 18" are fixed by piston 15 by means of the screw 17.

At the beginning of the work cycle, piston 5 is in contact with plate 10''' and is under the influence of the oil in room b, at the pb pressure. In the same time material 1 under the pressure of the same oil at the pressure pb, is interlocking with piston 5. at the same time, piston 15, under the arches 7 action that push draw bars 8, that are in contact with cylinder 16.

The work cycle begins with the pressure rise in room a to the value pa, what makes the pump plungers 22' and 23" to interlock material 1 with piston 15 and to determine the appearance of a axial compression force F1 of the material, equalized by the force F2 that is created by rhe oil in room b. The arch 7 force that pushes down axial the piston 15 on cylinder 16, has to be established so that the rise pressure pa, the friction force between the material and the half-jacks 18' and 18" to over-flow force F1 that pushes axial piston 15.

Maintaining the material in this position, sleigh 10, where are jacks 9 and 14, do the translation c, and sleigh 11 where is jack 12 do the translation d. Sideways 21 of the sleighs 10 and 11 are fixed on the bed frame of nanostructure equipment. We note with A the subsystem formed with piston 15 together with plungers 22' and 22", arch 30, half-jacks 2' and 2", stud nut 17 and draw bars 8, and with B the subsystem formed with piston 5, half-jacks 2' and 2" to interlock the material with piston 5. The two subsystems A and B are rejecting each other because of the arches 7. The shear movement c is made by the sleigh 10, with plates 10', 10" and 10''', together with cylinders 6 and 16 interlocked with this sleigh by screws 13, with the systems A and B, in these cylinders and with arches 7. Translations c and d take place after numerical controlled motion law and established with a program. In zones e and f of the material, appears a shearing, which amplitude, direction and speed are given by a motion law of X and Y axes with T trajectory in figure 1.

When the sleighs 10 and 11 are in the origin of axes XY, in room a being injected a quantity of oil q, that makes the system A, interlocked by the material with the system B, to misplace with cutting feed s. In figure 2 it is presented the case when there will be 4 oil injections, each injection with q quantity and determining misplace for both systems A and B and the material with the cutting feed s. The cutting feed s is adjusting with the zone width where the material is nanostructured after a nanostructure cycle, and of the zone numbers

where at a moment, the material is being nanostructured. The case presented in figure 2, is that where the number of shear zones n is 2, the zones e and f of the material.

A complete pass through of the way h and resetting in the initial position represents the work cycle of the equipment. The course h is being done by the subsystem 1 and the systems A and B, due to a large number of k consecutive misplaces with the cutting feed s. At the end of the course, piston 15 gets in contact with plate 10' of the sleigh 10, and piston 5 is being removed with the same course h reported to plate 10' of the sleigh 10, arch 4 is under compression. In this course, subsystems A and B consecutive take the positions I, II, III, IV and V. In each position subsystems A and B are staying unmoved and takes place a nanostructure cycle due to trajectory T.

To bring back in the initial position the subsystems A and B, the pressure pb in room b is decreasing, that makes the material to be more interlocked with the piston 5, and the arch 4 to bring back piston 5 in contact with plate 10" of the sleigh 10. In this position of the piston 5, the oil in room b is under compression again, at the pb pressure, thing that makes the material interlocked with the piston 5. the pressure in room a is continuously decreasing, so that the material not to be interlocked with the piston 15, and this, under the action of bars 8 are being pushed by the arches 7, to came back in the initial position, the material remaining interlocked with piston5. After the reverse motion of the piston 15 in initial position, the oil in room a is being under compression again, so that a new interlocking of the material 1 with the piston 15, and after that takes place the axial compression with the force F1 of the material. After the material has been nanostructure till the edge of it, it arrives in the situation when the material cannot be axial compressed with the force F1, due to jacks 18', 18" that not assure a friction force bigger than F1 force generated by the applied pressure pa of the piston 15.

Next, the material will be sheared in sections e and f, but without an axial compression by the force system F1 and F2. Piston 16 doesn't misplace the piston 15 anymore with the cutting feed s with the force F1, but with the bars 8 that compress to the edge the arches 7, after what they push the piston 5. After the material has passed the shearing zones, it can manually be extracted.
Pistonl 15 doesn't move piston 5 with the feed rate s by means of force F1and the part 8 which compress the springs 7. After this, the springs push the piston 5. After the moment when the workmaterial passed through the deformation

areas, the workmaterial can be reoved from the die.

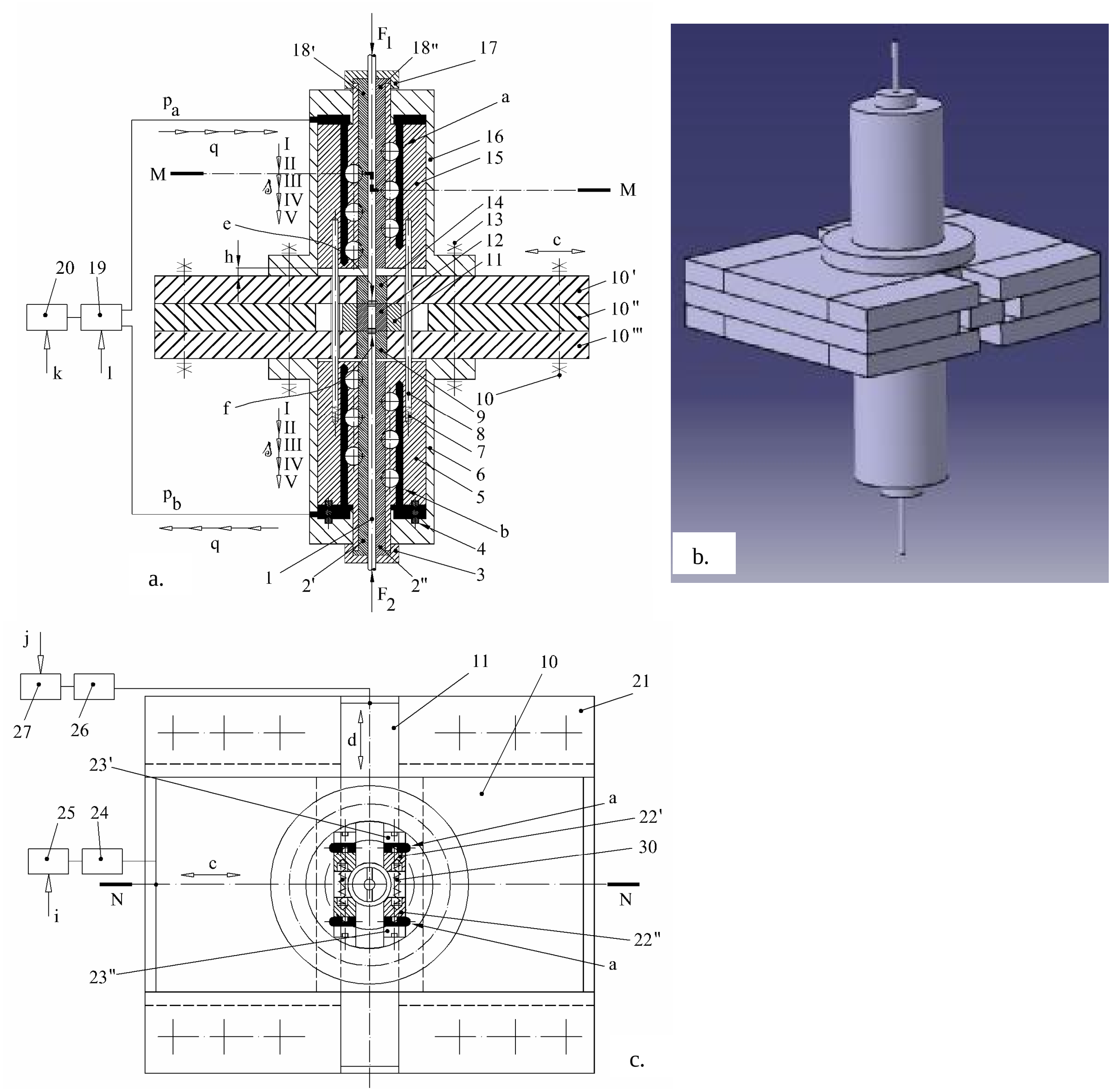

Figure 2 Multi-directional shear device
a. schematic draw of the device, b. main device of the nanostructuring equipment, c. view M-M

The equipment for nanostructuring the crystalline material will be used for severe deformation of the Al-Mg roads of 3 mm. the grain size and the new mechanical properties achieved by the new structure will be measured in the further researches. The designed equipment is presented in figure 3.

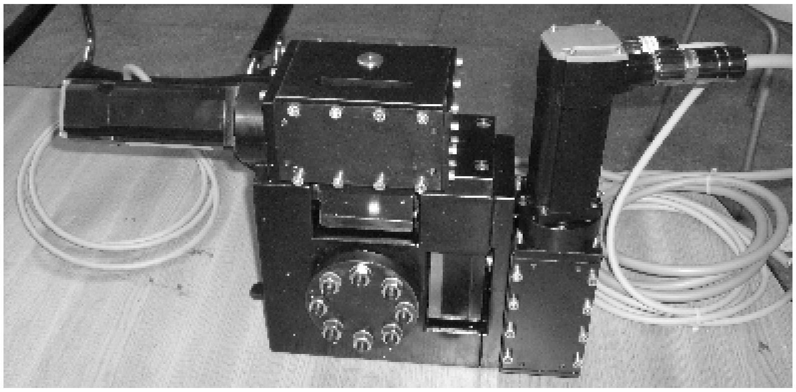

Figure 3 The designed equipment for multi-directional shear process

6. Conclusions

A new method of nanostructuring crystalline materials is proposed using the experimental-knowledge that the cumulated shear strain leads to diminishing the grain size. The method proposed is applied to aluminium roads of 3 mm diameters in order to obtain a ultrafine grained workmaterial for further applications such stomatological implants

Acknowledgements

The research was financed by the Romanian Ministry of Education and Research, CNCSIS, Grant A 686/2007 and Grant IDEAS 653/2008.

References

[1] L. Lu, M. L. Sui, K. Lu1, Superplastic Extensibility of Nanocrystalline Copper at Room Temperature, Science 287 (2000) 1463-1466.
[2] R. Valiev, Nanostructuring of metals by severe plastic deformation for advanced properties, Nature materials, vol 3 (2004) 511-516.
[3] R. Srinivasan, P. K. Chaudhury, B. Cherukuri, Q. Han, D. Swenson, P. Gros, Continuous Severe Plastic Deformation Processing of Aluminum Alloys, DOE Award Number: DE-FC36-01ID14022, Wright Stet University, Final Technical Repost, June 2006.
[4] A. Rosochowski, W. Presz, L. Olejnik, M. Richert, Micro-extrusion of ultra-fine grained aluminium, Int J Adv Manuf Technol, 33-1-2 (2007) 137-146.
[5] A. Rosochowski, Processing metals by severe palstic deformation, Solid State Phenomena, 101-102, (2005) 13-22.
[6] Nesterova, E. V., Bacroix, B., Teodosiu, C., Experimental observation of microstructure evolution under strain-path changes in low-carbon IF steel, Mater. Sci. Engng., A309-310 (2001) 495-499.
[7] R. Valiev, R. Islamgaliev, N. Yunusova, Superplasticity of Nanostructured Materials obtained by severe plastic deformation, Metal Science and Heat Treatment, 48, 47-53, 2006 (revista ISI).
[8] L. Olejnik, A. Rosochowski, Methods of fabricating metals for nano-technology Bulletin of the Polish Academy of Science, TECHNICAL SCIENCES, Vol. 53, No. 4, 2005
[9] R. Shankar, B. Rao, S. Lee, S. Chandrasekar, Severe plastic deformation of titanium at near ambient temperature, Acta Materialia 54, 3691-3700, 2006. (revista ISI)
[10] M. Banu , A. Tofan, V. Tabacaru, M. Cherif,C. Maier, V. Paunoiu, Qualitative analysis of the large plastic deformed Al-Mg alloy probe using atomic force microscopy, The Annals of University Dunarea de Jos of Galati, Fascicle V, ISSN 1221-4566 (2007) 125-129.
[11] M. Banu et al., Developying of a new nanostructuing method by multidirectional shearing process as a recursive chaotic process, Grant CNCSIS 686/2007, Romanian Ministry of Education and Research, Technical Report (2008).
[12] H.Haddadi, S. Bouvier, M. Banu, C. Maier and C. Teodosiu, Towards an accuarate description of the anisotropic behaviour of sheet metals under large plastic deformations: Modelling, numerical analysis and identification,, International Journal of Plasticity, Volume 22, Issue 12, 2006, Pages 2226-2271, Elsevier Science, ISSN: 0749-6419.

Conception et la fabrication d'un nouvel équipement pour réaliser nanostructures des métaux

Résumé

Ce papier présente la conception, design et la fabrication d'un nouvel équipement pour réalisée nanostructures des métaux – comme aluminium- par les processus de cisaillement multidirectionnelle. Changement de la trace de déformation produis le cisaillement des graines. En contrôlant le trace de la déformation et avec la possibilité de changement le trajet de déformation, le cisaillement augment jusqu'à 60% ce qu’il corresponde a un taille de grain de 100 nm. L’équipement de déformation permettre l’implémentation dans l’échelle industrielle de cette processus.

Proiectarea unui echipament pentru nanostructurarea metalelor prin forfecare multidirectionala controlata

Rezumat

Lucrarea prezinta proiectarea unui nou echipament de deformare plastica severa ce conduce la nanostructurarea materialului utilizat. Metoda de nanostructurare este propusa de autori, si se bazeaza pe forfecarea multidirectionala controlata a fiecarui punct material din sectiunea unui semifabricat. Acesta are forma de bara cu diametrul de 3 mm. Metoda este cobceputa, proiectata si materializata intr-un echipament de nanostructurare, ce ofera o metoda flexibila si uniforma de obtinere a unor microsctructuri cu proprietati superioare structurii cu graunti macroscopici.