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Original Research Article

Plastic flow of metals under cyclic change of deformation path conditions

Włodzimierz Bochniak, Andrzej Korbel, Paweł Ostachowski [*], Marek Łagoda

AGH – University of Science and Technology, Faculty of Non-Ferrous Metals, A. Mickiewicza Av. 30, 30-059 Cracow, Poland

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ABSTRACT

Reverse dislocation slip in metal, forced by cyclic change of deformation path (loading scheme), causes localized plastic flow with formation of dislocation dipoles which subsequently collapse leading to high concentration of point defects. Very low migration energy of point defects, especially self-interstitial atoms, indicating low bonding in a crystal lattice, favors low plastic flow viscosity which in turn leads to low flow stress and high plasticity (superplasticity) of metal. This paper presents the experimental results of KOBO extrusion and KOBO complex rolling, at low (room) temperature. The first method was used to produce thin wires made of $MgLi_4$ magnesium alloy (extrusion ratio $\lambda \sim 10\,000$), and fully compacted wires made of AZ91 magnesium alloy in the form of machining chips. Basing on the second method, it has been proved possible to change the mechanical properties of strips made of 7075 aluminum alloy without any reduction in their thickness.

1. Introduction

It is widely known, that the neutron irradiation of solids leads to the generation of an over-balanced concentration of point defects e.g. [1]. They are gathered into the form of nanoclusters, and their size, distribution and density determines their mechanical properties.

On the other hand, there is empirical evidence that clusters of vacancies and interstitial atoms also accompany high-speed, high-strain deformation [2–11]. Moreover, the absence of dislocations in heavily deformed metals, revealed during electron microscopic observations, allows to question whether the mechanism behind plastic flow is solely based on dislocations [8,12]. While researchers suggest that the dislocation free plastic flow is dominant, they do not seem to totally underestimate the role of dislocations in the deformation process. Dislocations play a particularly important role in generating point defects during processes accompanied by changes of the deformation path [13,14]. Unusually high, over-balanced concentration of point defects, particularly interstitial atoms with migration energy of 0.06–0.1 eV [15–17], intensifies recovery and recrystallization and as such leads to dislocation reduction.

The concept of stratified, rigid shear in shear bands of deformed metal has been presented in a paper [14]. They suggest that mechanism of plastic flow seems to be particularly active under the conditions of cyclic changes of the

* Corresponding author.
E-mail address: pawel.ostachowski@agh.edu.pl (P. Ostachowski).
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deformation path, which are met during the KOBO technological process [18,19]. The KOBO deformation being one of the severe plastic deformation (SPD) methods combines the main scheme of deformation – extrusion, rolling, forging or drawing, with an additional reverse deformation, which has no impact on the shape of the final product. The cyclic changes of the deformation path are accompanied by intense crossing of slips dislocations and forest dislocations, formation of jogs and bending of free dislocation segments leading to dipoles generation. The dipoles subsequently disintegrate and form areas (bands) saturated with point defects with weak atom bonds within the lattice, which is mainly the result of very low migration energy of the interstitial atoms. Hence, the lower viscosity (10^6 Pa s rather than 10^{19} Pa s) of bands within which the plastic flow of metal occurs, analogous to the viscosity of a Newtonian fluid (superplasticity). In other words, the metal ever remaining in a solid state, in the areas with over-balanced concentration of point defects is undergone an "easy" dislocation free rigid shear (shear bands).

The effect of post-deformation is both: (I) the partial annihilation of point defects and (II) the formation of clusters. Interestingly, the migration energy of clusters

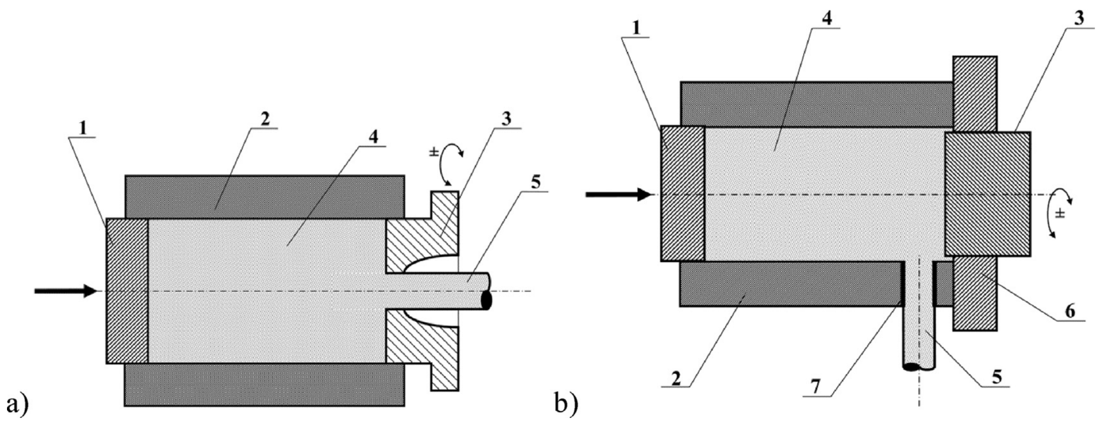

Fig. 1 – Schemes of direct (a) and lateral/angular (b) extrusion of metal by the KOBO method; 1 – punch, 2 – container, 3 – reversibly rotating die (a) or reversibly rotating mandrel (b) with ragging on front surface, 4 – extruded metal/billet, 5 – product, 6 – lock (b), 7 – die located on container's side surface (b) [30].

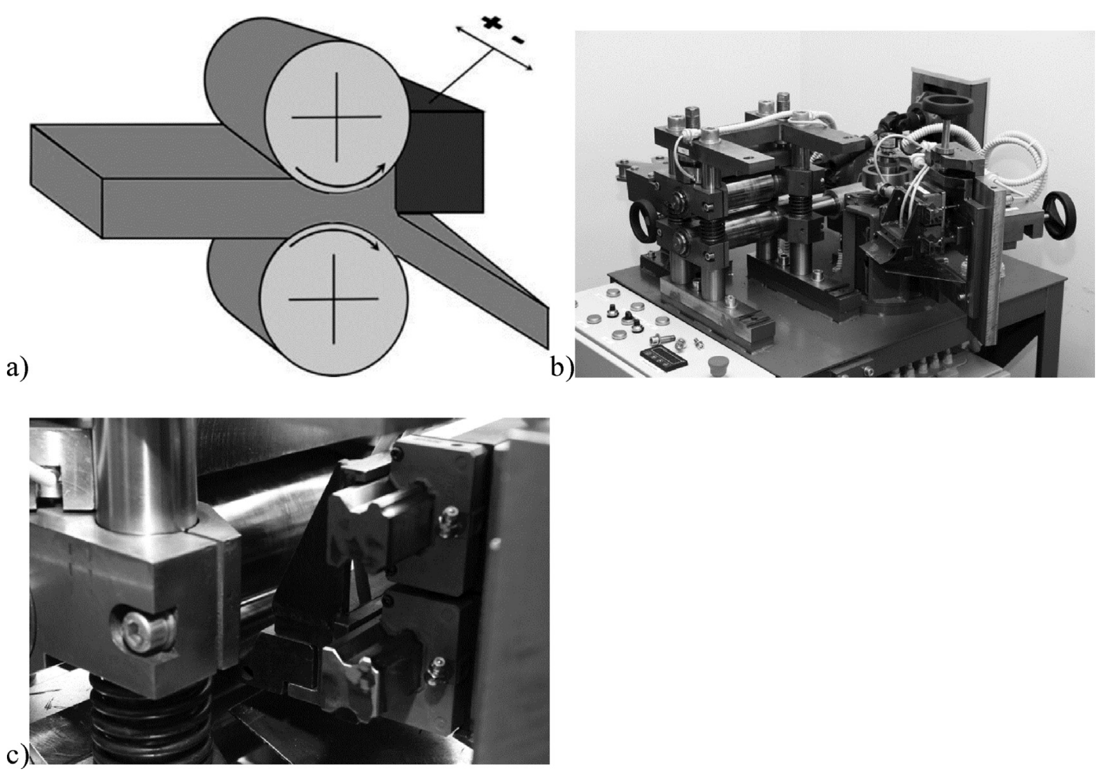

Fig. 2 – Complex rolling with cyclic changes of the deformation path (KOBO method). Process scheme (a), general view of device (b) and device details (c).