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PROCEEDINGS

Editors:
Ljubiša Balanović
Dejan Tanikić

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PREFACE

On behalf of the Organizing Committee, it is a great honor and pleasure to welcome all esteemed participants of the 54th International October Conference on Mining and Metallurgy (IOC 2023), scheduled to take place at the picturesque Bor Lake, Serbia, from October18th to 21st 2023.

The collaborative efforts of the University of Belgrade, the Technical Faculty in Bor, and the Mining and Metallurgy Institute Bor have meticulously organized this year's IOC. Our focus remains unwavering on showcasing the latest research findings and advancements in geology, mining, metallurgy, materials science, technology, environmental protection, and other engineering disciplines. Our primary objective is to foster a dynamic environment where academics, researchers, and industry professionals can come together to share their knowledge, experiences, and innovative ideas while exploring opportunities for collaborative research endeavors.

Our conference agenda is rich and diverse, encompassing plenary sessions, engaging invited lectures, technical presentations, enlightening oral and poster sessions, informative technical tours, a diverse exhibition, and memorable social gatherings. At the heart of this event lies our strong commitment to sustainable development within the mining and metallurgy sector. We are dedicated to exploring ecologically conscious methodologies, responsible resource extraction practices, and cutting-edge technologies that reduce the industry's environmental impact and enhance the well-being of local communities.

The conference proceedings comprise 129 papers authored by individuals from universities, research institutes, and industries in 22 countries. We are proud to welcome participants from Bosnia and Herzegovina, Bulgaria, Canada, China, Croatia, Germany, Greece, India, Iran, Kazakhstan, Libya, North Macedonia, Montenegro, Morocco, Romania, Russia, Slovakia, South Africa, Spain, Turkey, United States, and, of course, Serbia.

We are excited to host the 8th International Student Conference on Technical Sciences (ISC 2023) as part of IOC 2023. This event offers students from Serbia and the wider region a unique chance to showcase their research and discuss the future of their fields with experts.

We sincerely thank the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia for their generous financial support. In addition, we express our profound gratitude to all our sponsors, exhibitors, and friends of the Conference for their contributions and unwavering support for playing a pivotal role in ensuring the success of IOC 2023.

We would like to express our heartfelt thanks to all authors, committees, reviewers, speakers, and chairpersons for their invaluable contributions in shaping IOC 2023.

We look forward to welcoming you to the 55th International October Conference on Mining and Metallurgy (IOC 2024), which will be held in October 2024.

On behalf of the 54th IOC Organizing Committee,

Prof. dr Ljubiša Balanović

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EFFECTS OF COLD ROLLING AND ANNEALING PROCESSES ON THE MICROSTRUCTURE AND PROPERTIES OF MICRO-ALLOYED COPPER

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Abstract

In this paper, the change of mechanical and structural properties of micro-alloyed copper during the cold rolling and annealing process was monitored. Melting and casting of micro-alloyed copper was carried out in an electrical resistance furnace, with the "up-cast" casting process. The melted and chemically homogenized material was further subjected to the extrusion process, after which cold plastic deformation was performed with deformation degrees of 10, 30, 50 and 75%. Annealing of cold deformed samples was performed at 450°C for 35 min. The cooling of the samples was done in water with alcohol. After each stage of the experiment, the values of hardness, tensile strength and relative elongation were measured. The results showed that the values of hardness and tensile strength of unannealed samples increase with the increase in the deformation degree, while the relative elongation decreases. Deformation degree also affected the final grain size after the annealing process. At the highest deformation degree, the finest grains were obtained.

Keywords*: micro-alloyed copper, extrusion, plastic deformation, microstructure, mechanical properties.*

1. INTRODUCTION

Copper has excellent electrical and thermal conductivity, good plasticity, is easy to process, but at the same time has low tensile strength, hardness, wear resistance and fire resistance, i.e. slightly worse mechanical properties [1-4]. One of the procedures that can improve the mechanical and structural properties of copper and copper alloys is cold plastic deformation. Since it is a deformation with complete strengthening, the metal grains are strongly oriented in the direction of the deformation, i.e. in the direction of force action. The higher the deformation force, the more expressed the deformation texture.

Cold plastic deformation improves strength and hardness by changing the crystal structure, but reduces toughness and plasticity, which easily creates residual stress. The subsequent annealing process after cold deformation results in dynamic recrystallization, which can produce the desired grain sizes and properties [5]. The loss of formability and ductility during cold rolling can be recovered during annealing [6].

In this work, the mechanical properties of micro-alloyed copper deformed at different degrees of cold deformation, as well as the change in microstructure after the subsequent annealing process, were investigated.

2. EXPERIMENTAL

Deoxidized low-phosphorus copper (DNP-Cu) with a maximum iron content, Fe up to 0.003 wt% and a maximum phosphorus content, P up to 0.014 wt% was used as the starting material. In order to obtain material of this chemical composition, copper cathodes with a purity of 99.99 % Cu were used, which were melted in an electrical resistance furnace with a protective atmosphere, and then casting was performed using the "up-cast" process. Copper microalloying was performed by adding prealloy CuP6.42 and adding iron in the form of powder. Cast rods of satisfactory chemical composition were subjected to the extrusion process, resulting in strips 90 mm wide and 19.8 mm thick. After obtaining the extruded samples, rolling was followed on a rolling mill with smooth rollers from the manufacturer "FIOA - Italy" with reduction degrees of 10, 30, 50, and 75%, up to the final thickness of the copper plates of 4 mm.

After each phase of the experiment, the hardness measurement was carried out on the device for measuring the hardness of the manufacturer "VEB Leipzig", as well as the measurement of the tensile strength and elongation on the tear machine "OTTO WOLPERTWERKE GmbH".

The metallographic preparation of the samples was carried out on the "METKOM ELOPREP 102" electrolytic polishing and etching device. An aqueous solution of phosphoric acid and alcohol was used as an electrolyte for polishing the samples, and for better structure development, the samples were also etched with a solution of ferric chloride.

Microstructural analysis of the prepared samples as well as statistical grain counting was performed on a "LEICA" microscope equipped with a "Flexcam - C1" digital camera.

3. RESULTS AND DISCUSSION

Table 1 shows the results of tensile tests and hardness tests of samples in the unannealed and annealed state. As the degree of deformation increases, hardness and tensile strength increase as a result of deformation strengthening, while relative elongation decreases. During plastic deformation, dislocations react with each other and form immobile dislocations, which are an obstacle to the movement of other dislocations. With the advancement of dislocations, the number of obstacles increases, so it is necessary to apply a higher force in order to continue deformation [7, 8].

Table 1 - Mechanical properties of unannealed and annealed samples at different degrees of deformation

Sample condition	Deformation degree ε (%)	Hardness (HV)	Tensile strength R_m (MPa)	Relative elongation A (%)
Extruded	0	50,12	207,00	61,50
Deformed, not annealed	10	86,11	258,80	40,00
	30	106,50	336,60	11,25
	50	112,50	372,00	7,50
	75	121,20	381,80	6,25
Deformed, annealed for 35 min. at 450°C	10	45,46	228,50	54,37
	30	47,15	231,60	55,00
	50	48,00	236,50	53,75
	75	49,03	240,40	50,00

The maximum value of hardness and tensile strength was reached at the highest degree of deformation (75%) and for hardness it was 121.20 HV, while the tensile strength was 360 MPa. During the tensile test, the same sample broke with a very small elongation of 6.25%, which is a consequence of the loss of ductility in the cold rolling process.

The subsequent annealing process after cold deformation results in dynamic recrystallization, with a drop in hardness and tensile strength, and an increase in relative elongation.

The level of deformation also affected the final grain size after the annealing process. Figure 1 shows the microstructures of samples with different degrees of deformation after annealing at 450°C for 35 min. It can be concluded that the higher the level of deformation, the finer the grain size after the annealing process, which was confirmed by the statistical analysis of grain counts.

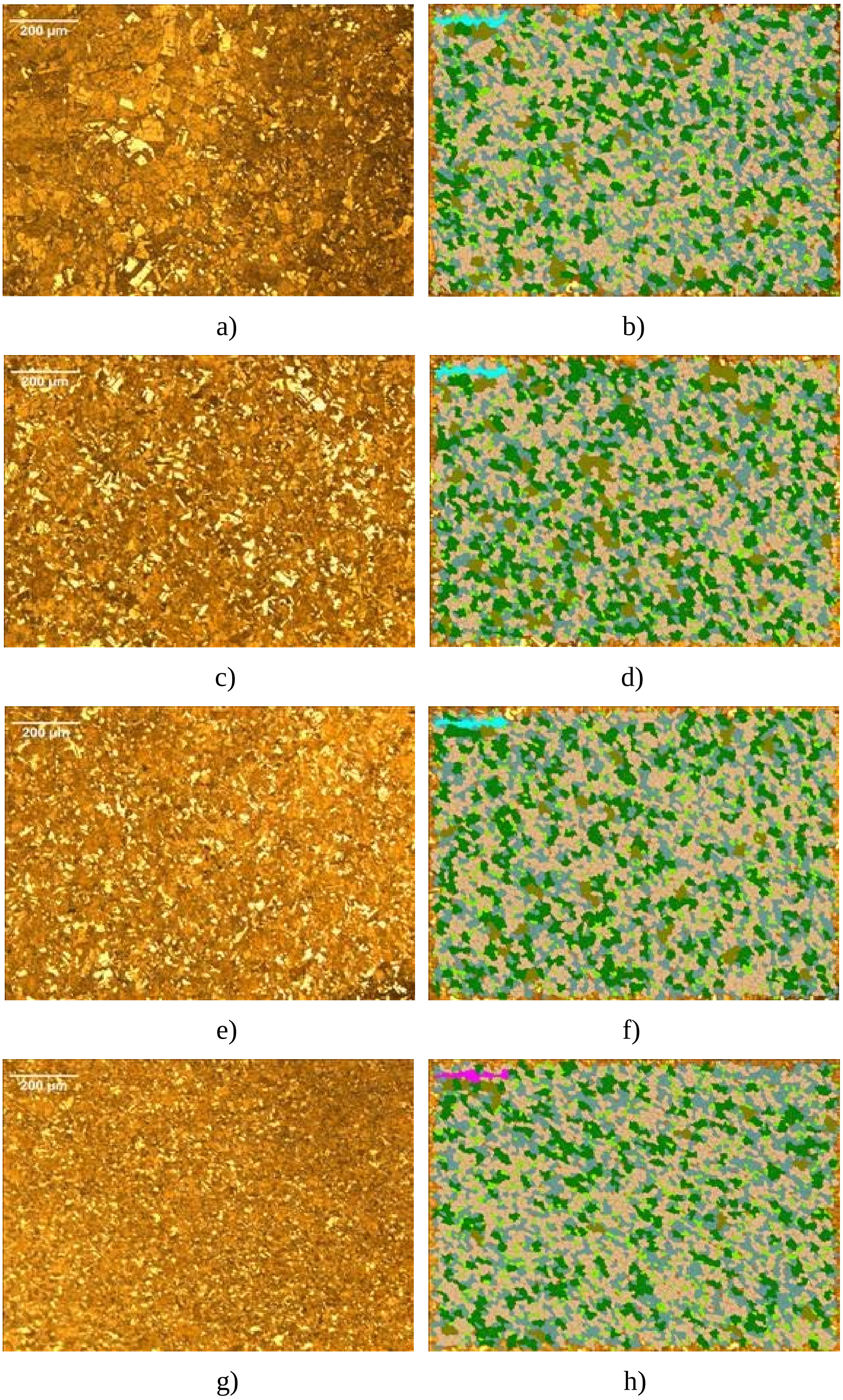

Figure 1 - Optical microphotographs of samples annealed for 35 min. at 450°C with different degrees of deformation: a) deformation degree 10 % with b) grain counting statistics, c) deformation degree 30 % with d) grain counting statistics, e) deformation degree 50 % with f) grain counting statistics, g) deformation degree 75 % with h) grain counting statistics

The deformation process introduces dislocations and texture in the microstructure. Subgrains in between shear bands and twinning may act as nucleation sites for new grains. Therefore, higher deformation leads to higher grain nucleation rate that ends as finer grains after annealing process.

4. CONCLUSION

Based on the conducted research, the following conclusions can be drawn:

- The hardness and tensile strength of microalloyed copper during cold rolling increase with the degree of deformation due to strain hardening, while the relative elongation decreases. The maximum values of hardness and tensile strength were obtained at the highest degree of deformation (75%) and they were 121.20 HV and 360 MPa. Due to the fact that the material lost its ductility in the cold rolling process, the relative elongation of the sample with the highest degree of deformation was only 6.25%.
- During the annealing process at 450°C for 35 min., due to the mechanism of recovery and release from stress, recrystallization and grain growth, there was a decrease in values for hardness and tensile strength, and an increase in relative elongation.
- The degree of deformation also affected the final grain size after the annealing process. As the degree of deformation increased, the structure became finer.

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