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Flow forming and recrystallization behaviour of CuZn30 alloy

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Abstract. CuZn30, which is also called cartridge brass, is an alloy used commonly in the production of large-calibre round cartridge cases. They are usually produced via cupping of a disc and consecutive deep drawing steps to decrease the wall thickness, with an annealing process in between each step to restore formability. In this study the manufacturing of cartridge brass (CuZn30) tubes is conducted through the flow forming process. In order to evaluate the flow forming behaviour, the preforms are manufactured by machining the CuZn30 billets, then the flow forming processes is applied. Thereafter, different temperature ranges (350, 450, and 550ºC for 1 h) are applied to flow formed samples in order to determine the proper recrystallization annealing temperature. The obtained microstructures and the mechanical properties are studied and revealed that the flow forming process is successfully realized, and the microstructure of the material is mapped with respect to the subsequent heat treatment temperature for recrystallization. Spherical and new grains are precisely generated after recrystallization annealing at 450 and 550ºC, but only partial recrystallization is obtained at 350ºC.

Introduction

The alloy CuZn30, also known as cartridge brass, is best known for its use in the production of large-calibre round cartridge cases. In order to reduce the wall thickness in a series of deep drawing steps, they are typically produced by cupping a disc, followed by each deep drawing step being followed by an annealing step to regain formability [1].

Flow forming could also be a suitable alternative method for decreasing the wall thickness of the case. It is an efficient technique for manufacturing precision tubular products and is an incremental forming process in which the wall thickness of a product is decreased by passing rollers over the material once or multiple times [2]. For the flow forming process, in addition to process parameters such as the feed rate, rotation speed, and reduction ratio, which concern the process window, material properties are also a major factor that determines the process outcome. Bylya et al. [3] investigated the influence of the elastic-plastic properties on the formability of the material and pointed out resilience, strain hardening, and tensile area reduction as significant parameters, which affect the material's ability to redistribute its volume along the mandrel. For a material with high strain hardening, the deformed material at the top strengthens and restricts the upward elastic expansion of the material at the bottom. This directs the expansion along the mandrel and allows large elongations under hydrostatic compression. A higher resilience means a higher elastic compression and, therefore, expansion.

Cartridge brass has excellent cold forming and high strain hardening capability. However, its resilience is not as high as for example high strength steel due its lower yield strength. In this work, the flow forming behaviour of CuZn30 is studied considering its plastic properties within the scope

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of cartridge case production as well as its recrystallization behaviour to determine the optimum process for the best final product. Heat treatment is required in between the cold forming steps for further forming by recrystallization and is usually done at around 500 to 650ºC for the deep drawing processes according to reduction ratios. [4].

Experimental Procedure

CuZn30 alloy is procured in hot extruded condition. Optical emission spectroscopy is employed to confirm the material grade. The material composition matches with the composition of CuZn30 (C26000) according to ASTM B19 as seen in Table 1 [5].

Table 1. Chemical composition of the preform.

	Zn	Pb	Sn	P	Fe	Ni	Al	Bi	Cu
Value [%]	28.67	0.022	0.014	0.004	0.023	0.01	0.0027	< 0.001	71.2066

Fig. 1 Preform (PRE) part on the left and Flow-formed (FF1) on the right.

For the flow forming operations, the materials are machined into preforms in the form of hollow cylinders closed at one end with an outer diameter of 125.20 mm, wall thickness of 5.2 mm and a length of 300 mm. Preform is then flow formed with a feed rate of 110 mm/sec and rotation speed of 160 rpm with 40% thickness reduction ratio at one cycle which are illustrated in Fig.1. In this work, a preform and a flow formed parts are investigated through the microstructural analysis and the mechanical testing. Metallographic specimens from longitudinal and transverse sections for each case is prepared according to ASTM E3 [6]. The specimens are etched with Klemm's III Reagent 3 minutes and Acidic Ferric Chloride 1 minute by immersion, separately. After etching, microstructures are analyzed under an optical microscope, Olympus BX53M. The hardness measurements are conducted with a Vickers micro indentation method using EmcoTest DuraScan – 20 according to ASTM E384 [7]. For longitudinal and transverse sections of specimens, the hardness is measured 10 times, starting from the forming surface in contact with the rollers, along the diameter at specified intervals. Tensile testing specimens are prepared by machining as shown in Fig. 2 and tested three times according to ASTM E8 [8] using an Instron 3382 model Universal Testing Machine.

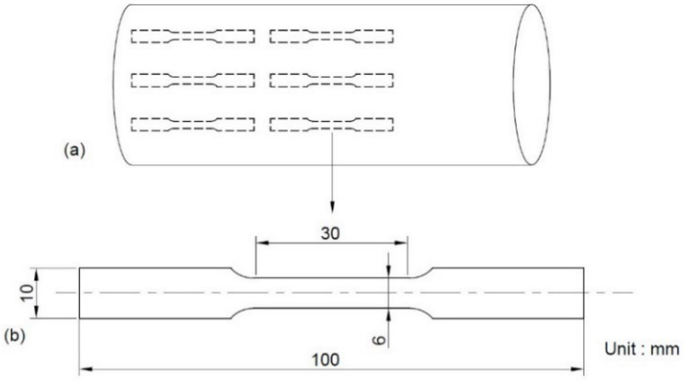

Fig. 2. The cutting position of the specimen for tensile testing (a); and (b) the specimen dimensions for tensile testing.

To investigate the recrystallization behaviour, flow formed samples (abbreviated as FF1) with dimensions around 5x5 cm are cut for microstructure analysis and hardness measurements and tensile testing specimens are machined from the preform and the flow formed parts. After manufacturing the specimens, analysis and testing are carried out, afterwards, the specimens are subjected to recrystallization heat treatment by open atmosphere laboratory furnace. The data given for 40% cold worked CuZn30 (FF1) is used as a reference for determining the recrystallization heat treatment temperature. However, the recrystallization behaviour is expected to vary with the amount of cold work as plastic deformation increases the internal energy of the material. Three heat treatment temperatures, 350, 450 and 550°C, are determined for examination. The specimens are heated with a rate of 10°C/min and held at the respective temperatures for 1 hour followed by air cooling. Microstructure analysis, hardness measurements and tensile tests of the heat-treated specimens are carried out accordingly.

Results and Discussions

The hardness of the preform is measured in the range of 75 – 85 HV. After the flow forming process, the hardness increased to 190 – 235 HV. Near the outer surface where the rollers contact occur, hardness is around 235 HV, and it drops to 190 HV at the inner surface which is in contact with the mandrel. The amount of deformation is higher at the outer surface where the force is applied by the rollers. The hardness values obtained from the longitudinal sections are similar to the transverse section. Microstructure image taken from the preform is presented in Fig. 3. CuZn30 contains approximately 30% Zn. At this concentration, only α phase forms in the microstructure. As illustrated inn Fig. 3, α grains and annealing twins are observed.

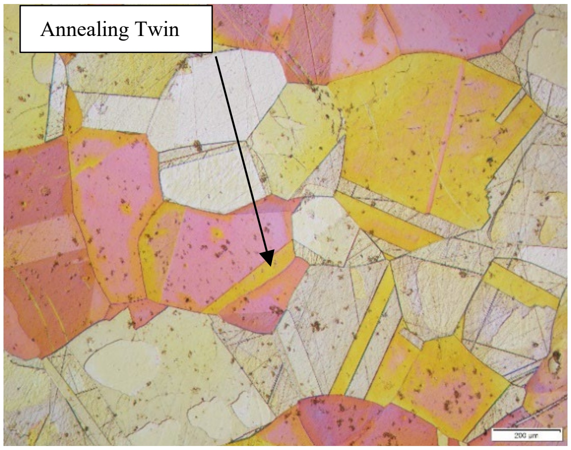

Fig. 3. Microstructure images from transverse cross-sections of PRE-specimen at 100X, Klemm's III Reagent-3min.

The microstructures of flow formed FF1 samples are presented in Fig. 4. The effective hardening mechanism in CuZn30, which consists of a single phase, is deformation hardening. Since α phase has a low stacking fault energy, it is difficult for screw dislocations to perform a cross-slip. Due to this restriction in dislocation movement, the material has high strain hardening properties [9].

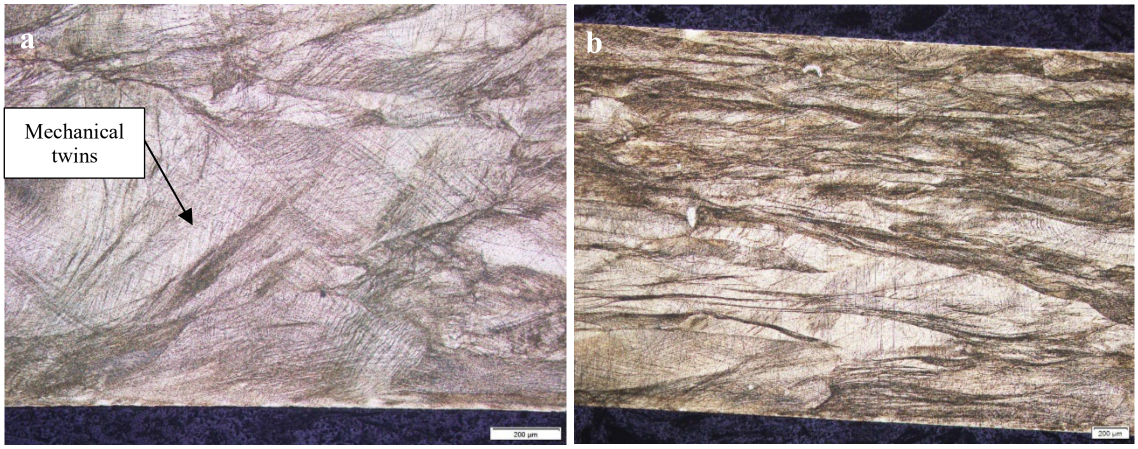

Fig. 4. Microstructure images from transverse cross-section of FF1 specimen at (a) 100X and (b) 50X, Acidic Ferric Chloride-1min.

Since slip systems are limited in materials with low stacking fault energy, mechanical twins are observed in microstructure after the deformation. In flow formed sample (FF1), the mechanical twins are seen as thin parallel lines side by side. These are the local high shear strain zones seen in ductile materials that caused by a high amount of deformation [10]. The ultimate tensile strength (UTS) hardening exponent n of flow-formed (FF1) is calculated as 0.12 and as for the preform (PRE), it is calculated as 0.48. This shows that the preform has a higher strain hardening ability compared to FF1 specimen.

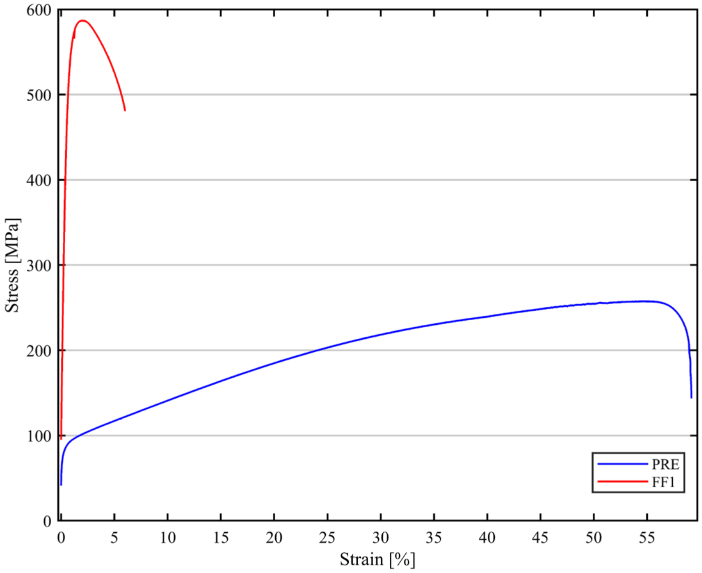

Fig. 5. Stress-strain curves of PRE and FF1 specimens.

The hardness values of heat-treated parts at 350, 450 and 550ºC, are measured between 120 – 130 HV, 90 – 110 HV and 75 – 90 HV respectively. The hardness dropped to preform hardness values after heat treating at 550ºC. The microstructure of heat-treated samples at 350ºC, 450ºC and 550ºC are given in Fig. 6, 7 and 8 respectively. The microstructure of the transverse, longitudinal and planar sections are similar to each other. As shown in Fig. 6, the mechanical twins did not completely disappear in FF1 after the heat treatment at 350ºC. Grain morphology could not occur completely in microstructure, but it could be observed that the number of mechanical twins decreased and partial recrystallization occurred. The recrystallization of FF1 can be completed by increasing the heat treatment time at the application temperature. The microstructures after the heat treatment at 450°C and 550°C are presented in Fig. 7 and 8 respectively. It is observed that recrystallization has taken place in the microstructure. At the higher heat treatment temperature, the grain sizes increased as shown in the figures.

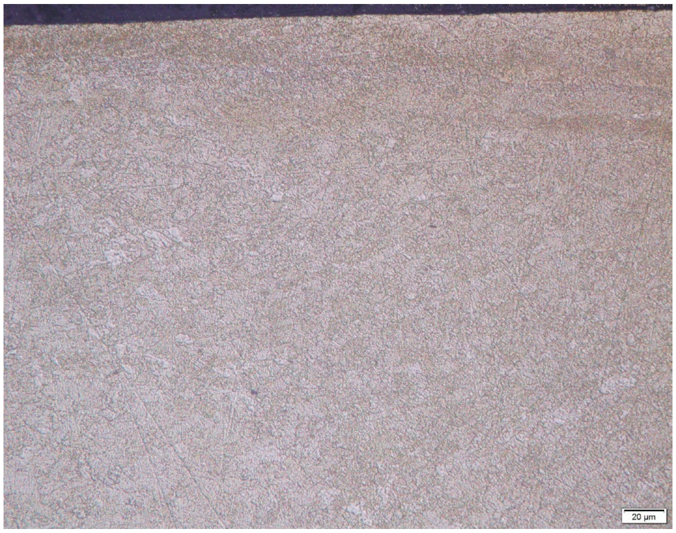

Fig. 6. FF1 heat treated at 350ºC taken at 500X, Acidic Ferric Chloride-1min.

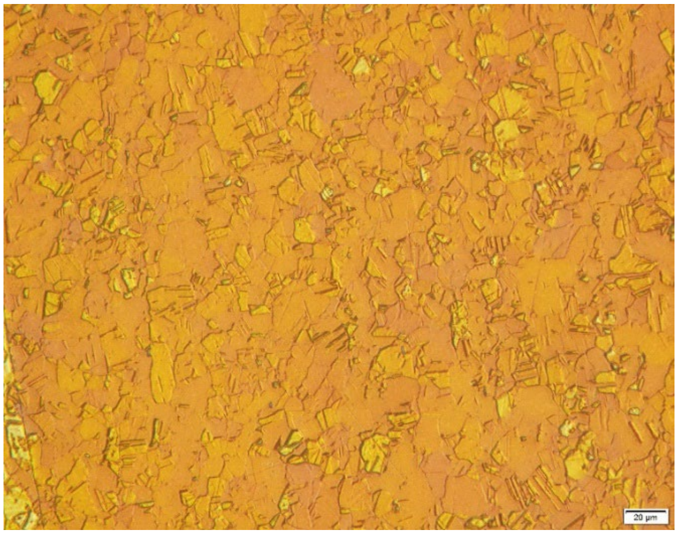

Fig. 7. FF1 heat treated at 450 ºC taken at 500X, Klemm's III Reagent-3min.

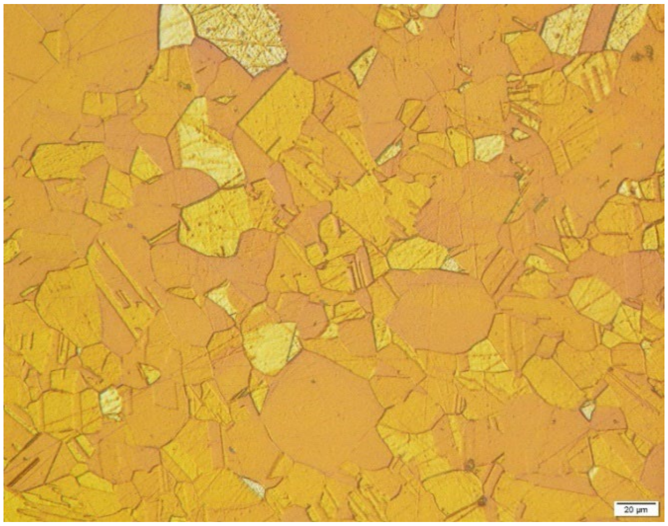

Fig. 8. FF1 heat treated at 550 ºC taken at 500X, Klemm's III Reagent-3min.

The tensile test results of the heat-treated samples are shown in Fig. 9 As the heat treatment temperature increases, the strength of the material decreases and its ductility increases. The strength level of FF1 specimen heat treated at 550°C approaches quite close to the strength levels of preform.

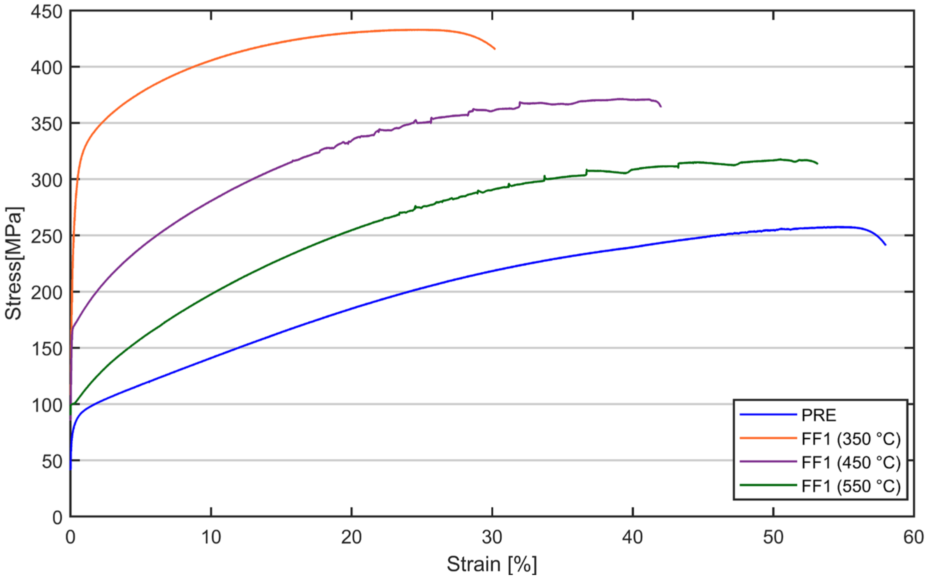

Fig. 9. Stress-strain curves of recrystallization heat treated specimens.

Summary

This paper investigates the formability of cartridge brass using flow forming process as well as the behaviour of recrystallization following cold deformation by heat treatment at three different temperature levels, which are 350°C, 450°C, and 550°C. After the flow forming process, a substantial strain-hardening is obtained, with tensile strength increasing twofold and yield strength increasing fivefold, while elongation decreasing to 5% from 55%. This elongation level makes the material quite brittle, therefore, it is very difficult to use the cartridge brass at this elongation levels because of its low toughness. In order to eliminate brittleness, both recrystallization and annealing procedures are carried out. The annealing processes are applied at three different temperature values. Microstructural analysis and mechanical testing revealed that the recrystallization process succeeds at 450°C and 550°C, while recrystallization could not be completely affected at 350°C. As for tensile testing of the FF1 specimen, which is annealed at 350°C, it is observed that elongation increases which could be related to recovery. The recrystallization mechanism necessitates more temperature in order to lower dislocation density; therefore, only the recovery mechanism occurs at 350°C.

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