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Effects of Cold Extrusion on the Mechanical Properties of Scrapped Copper Coil

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Abstract. The recycling of copper coil into finished products via sand casting with subsequent cold extrusion was investigated. This paper examined the effects of cold extrusion on the mechanical properties of the scrapped copper coil using a locally manufactured extruder with a conventional face die. The mechanical properties tested on the extrudates are limited to hardness, tensile, and compressive strength. The results reveal that the hardness of extruded copper of 11.10 mm and 11.45 mm improved significantly by 39 % and 41 %, respectively, compared with respective non-extruded copper. The compressive and tensile strength increases by 42 % and 22 %, respectively, for 11.10 mm extruded copper compared with the corresponding non-extruded copper. Also, the elongation of the extruded copper of 11.10 mm and 11.45 mm increases by 33 % and 34 %, respectively. It was deduced that the extruded copper is more ductile than the non-extruded copper. The micrograph reveals that grains in non-extruded copper are relatively coarse and nonuniform with voids, but fine and relatively uniform grains are obtained in extruded copper. The grains are refined during cold extrusion, and voids and dislocations are reduced significantly.

Keywords: billet, extrudate, extrusion, die, deformation.

1 Introduction

Scrap metals, machining chips, and coils which are environmental nuisance and contaminants can be recycled into ingot or die-casting products using different metal forming processes to reduce environmental degradation [1]. Scrap materials can be recycled with remarkable properties through processes like rolling, extrusion, and forging [2].

Copper is a non-ferrous metal with a reddish appearance, and it has an excellent conductor of heat and electricity with a crystal structure of face-centered cubic (FCC) [3, 4]. The copper present in pre-alloyed iron powder (comprising copper, nickel, and molybdenum) boosts hardenability and strength in the powder metallurgy part [5].

Extruded materials possess a combination of properties such as high strength and density, high ductility, good workability and weldability [6], high hardness, tensile and compressive strength [7], yield, and ultimate tensile strength [8]. Severe plastic deformation methods can produce ultrafine-grained material with high ductility and strength [9].

Impact test on specimens parallel to the direction of rolling demonstrated a higher impact toughness value in contrast to the specimen perpendicular to the direction of rolling [10].

Extrusion involves compacting metal scraps, chips, and coils into billets through a die to produce extrudates of the constant cross-section according to the profile of the die orifice [11]. An increase in die angle decreases the extrusion load. The surface roughness and hardness increased with the die angle [12]. The grain size of copper tubes under hydrostatic extrusion increases as the extrusion ratio increases [13].

The processing parameters of ECAP, such as extrusion pass, die angle and pressing velocity, affect the mechanical properties [14]. The ductility of aluminum chips extruded with solid rectangular profile through porthole dies increased compared to the profile extruded through a flat-face die [6]. The annealing twins available after the hot extrusion in powder metallurgy materials deteriorate after cold working [15].

2 Literature Review

Many researchers have studied the mechanical properties and microstructural analysis of extruded metals. Kahlani and Jafarzadeh [16] investigated the mechanical properties and microstructure of bimetallic Al-Cu composite rods fabricated via the spiral extrusion technique. The experimental results show that the bonding quality of the specimen increased due to the application of spiral extrusion. Lv et al. [17] analyzed the $CuAl_7$ alloy plane micro spring fabricated through the cold extrusion process using a micro-extrusion die. The micro spring microstructure depicted the equiaxed grains with both internal and surface cracks.

Berndt et al. [9] investigated the effect of cold and warm extrusion on the microstructure and mechanical characterization of cylindrical rods that were extruded from cast billets of an AA6060 aluminum alloy at room temperature (RT) and 170 °C (aging temperature of the alloys) respectively. Li et al. [18] experimentally investigated the microstructure changes of Al-Mg-Si alloys produced via hot extrusion and cold rolling. The results showed that the grain growth and dynamic recrystallization occur during hot extrusion, resulting in coarse and equiaxed grain structure.

Vignesh et al. [19] studied the influence of hot extrusion on grapheme platelets (GNPs) dispersed aluminum composites. The result showed that the strain hardening exponent and strength coefficient values of aluminum composites with 1.5 wt % GNPs dispersion produced by hot extrusion was two times higher than aluminum and non-extruded Al-GNPs composites. Chen et al. [20] studied the evolution of the microstructure and texture in copper processed via repetitive extrusion-upsetting (REU) and subsequently annealed at different temperatures. There were significant changes in grain morphology and crystallographic texture during the REU process.

Adequate lubrication is needed in the cold extrusion process because it reduces extrusion loads and wear. It also improves the tool life and quality of the products [21]. Kamitani et al. [22] evaluated the performance of different lubricants for producing products with smooth surfaces during the cold extrusion process. Their findings showed that the smooth surface roughness of the billet was retained when paraffinic mineral oil was used as a lubricant.

Another manufacturing process involved in this study is casting. This method involves the process in which molten metal flows into the mold due to gravity or another force, and the molten metal is cooled and solidified according to the form of the mold [3, 23, 24]. One of the techniques of the casting of metals is sand casting. Sand casting involves pouring molten metal into a mold made from a mixture of sand and solidifies in the mold at room temperature [25]. It has a rough surface finish, dimensional inaccuracy, and occasional surface impurities [26]. The low crystallization rate in sand casting of copper silumins leads to the development of a rough microstructure that is consequently accountable for relatively low strength and ductility [27].

The mold is usually made of sand particles bound together with an inorganic agent like resin-bonded, green sand, clay binder. [23]. This process is also relatively cheap and suitable for producing metals with complex shapes in a low production volume [28].

This research investigates the effect of sand casting and cold extrusion on the mechanical properties and microstructure analysis of scrapped copper coil using a locally manufactured extruder. The mechanical properties tested on the extrudates are limited to hardness, tensile, and compressive strength.

3 Research Methodology

3.1 Material preparation

The material used in this research was scrapped copper coil, which was thoroughly cleaned. Acetone was further used to remove impurities and stains from the copper scraps. The elemental composition of the scrapped copper coil is indicated in Table 1 using optical emission spectroscopy.

The materials were pounded into small shapes and sizes to be easily accommodated by the crucible pot before being put into the pit furnace for casting.

Table 1 – Elemental composition of the scrapped copper coil, wt %

Zn	Cu	Pb	Si	Ni	Fe	Co	Al	Sn	P
0.02	99.5	0.015	0.15	0.04	0.03	0.04	0.01	0.02	0.05

3.2 The casting of the sample

The casting process adopted in this study was sand casting. The sand mold was used to form a cylindrically shaped mold cavity which was crushed to remove the cast copper.

The sand was packed around the pattern to create the mold. The copper scrap was fed into a crucible pot and heated to about 1120 °C.

The molten copper was charged into the mold and cooled at room temperature for solidification.

The cast sample (copper) with the dimensions from 20 mm to 18 mm tapered diameter and 120 mm long was fixed on the 3-jaw chucks lathe machine and machined to the dimensions of 16 mm diameter and 120 mm long as shown in Figure 1.

Figure 1 – Machined copper sample

3.3 Cold extrusion of cast copper

Cold extrusion of cast copper was carried out on a locally fabricated extruder. The locally manufactured extruding machine is situated at the Department of Mechanical Engineering, Kwara State University, Malete, Nigeria. The conventional flat face die was employed during cold extrusion under the extrusion ratio of 1.14. The die of 14 mm diameter was used to extrude the copper rod that was machined to 16 mm diameter. The ram of the extruder was lubricated correctly to reduce the friction between the barrel and ram/piston. The copper billet was inserted between the ram and die. Then the barrel cover was closed and tightened to the endpoint of the barrel to provide a barrier that prevents the free fall of the die. The extrusion machine was powered electrically, and the electric motor was operated with an adjusted speed of 450 rpm. Then a copper extrudate with a final diameter of 14 mm is produced, as shown in Figure 2.

Figure 2 – Extruded copper

The two samples that were provided for testing are stated in Table 2.

Table 2 – List of samples provided for testing

Sample	Copper type	Rod diameter, mm
A	Non-extruded	11.10
B	Extruded	11.10
C	Non-extruded	11.45
D	Extruded	11.45

3.4 Testing of mechanical properties and microstructural analysis

Tensile strength testing of all specimens was conducted under ASTM E8/E8M-11. Two identical test specimens for each section thickness per sample were tested at room temperature with a strain/ loading rate of 5 mm/min using a computerized Instron Testing (model 3369). The Brinell hardness test was performed according to ASTM E10-18. Using a Brinell hardness tester, the test was done on the extruder and non-extruded copper samples. Compressive test analysis was carried out on all the samples at room temperature using a Universal Testing Machine (UTM). This was done according to ASTM E9. Each of the specimens was placed on the jaw of UTM one after the other. Loads of 2.5 kN and 4.7 kN were then applied to each copper sample until the specimen failed.

The samples were grounded using silicon carbide papers of different grades 220, 320, 400, and 600 grits and polished with cloth swamped with the solution of 0.5 µm Silicon carbide until a mirror-like surface was attainable. The samples were subsequently etched with 2 % NITAL (2 % Nitric Acid and 98 % Ethyl Alcohol) and dried in desiccators. The microstructure of the samples was characterized by light optical microscopy under polarized light.

4 Results and Discussion

4.1 Compressive test

The compressive test was carried out on the samples (11.10 mm) for non-extruded and extruded copper. Figure 3 presented the graph of compressive stress against the compressive strain (mm/mm) of all the samples.

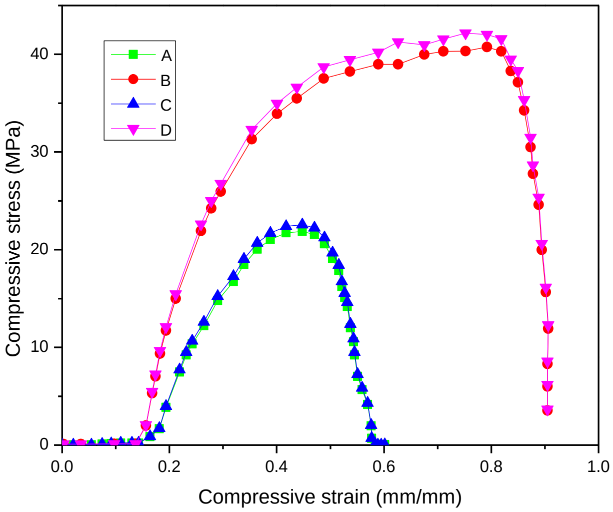


Figure 3 – Compressive strength for all the samples

The maximum compressive strength for samples A, B, C, and D is 22.0 MPa, 37.6 MPa, 23.2 MPa, and 41.3 MPa, respectively.

The study revealed that the maximum load-bearing capacity, compressive strength, and breaking a load of sample B increase by 43 %, 42 %, and 94 %, respectively, when compared with sample A.

4.2 Tensile test

The tensile test results (stress/strain curve) of the copper samples before and after extrusion are presented in Figure 4, respectively. The maximum load-bearing capacity, the ultimate tensile strength, and breaking load for sample A (non-extruded copper) are 3.48 kN, 271.0 MPa, and 46.8 N, respectively. The maximum load-bearing capacity, the ultimate tensile strength, and breaking load values for sample B (extruded copper) is

5.20 kN, 348.0 MPa, and 736.8 N, respectively. The study revealed that the extruded copper's maximum load-bearing capacity, tensile strength, and breaking load increased by 33 %, 22 %, and 94 %, respectively. Also, the elongation of the extruded copper of 11.10 mm and 11.45 mm approximately increases by 33 % and 34 %, respectively, compared with the corresponding non-extruded copper, as shown in Figure 4. It can be deduced from the analysis that the extruded copper is more ductile than the non-extruded copper.

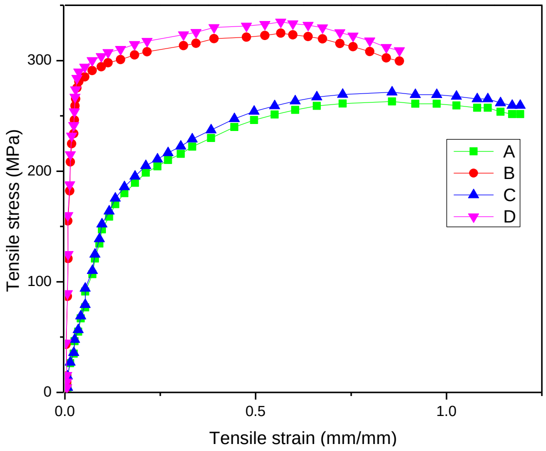


Figure 4 – Tensile strength for the copper samples

4.3 Hardness test

The hardness test was carried out on each sample of copper. The test was performed on a Brinell hardness tester. The tests carried out on the samples were presented in Figures 5–6.

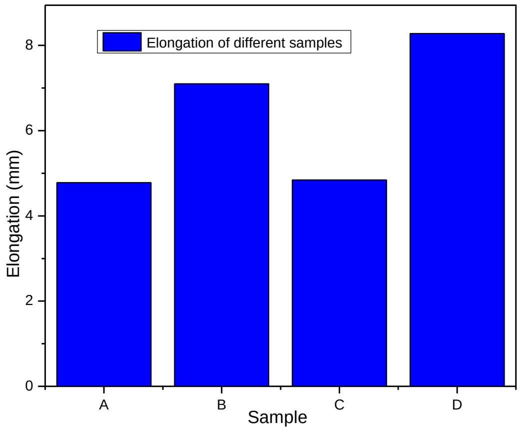


Figure 5 – Elongation for the copper samples

The values recorded for sample 11.10 mm (non-extruded and extruded) copper increases from 49.7 BHN to 69.1 BHN. Therefore, it can be inferred that the hardness of the extruded copper has a reasonable increment compared to the material before extrusion. The hardness improved significantly by 39 % and 41 % for extruded copper of 11.10 mm and 11.45 mm, respectively, compared with respective non-extruded copper.

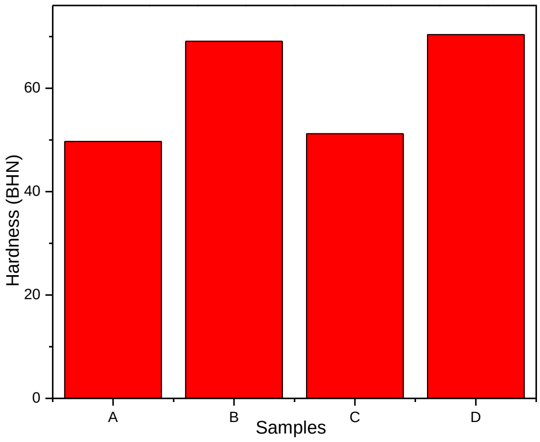
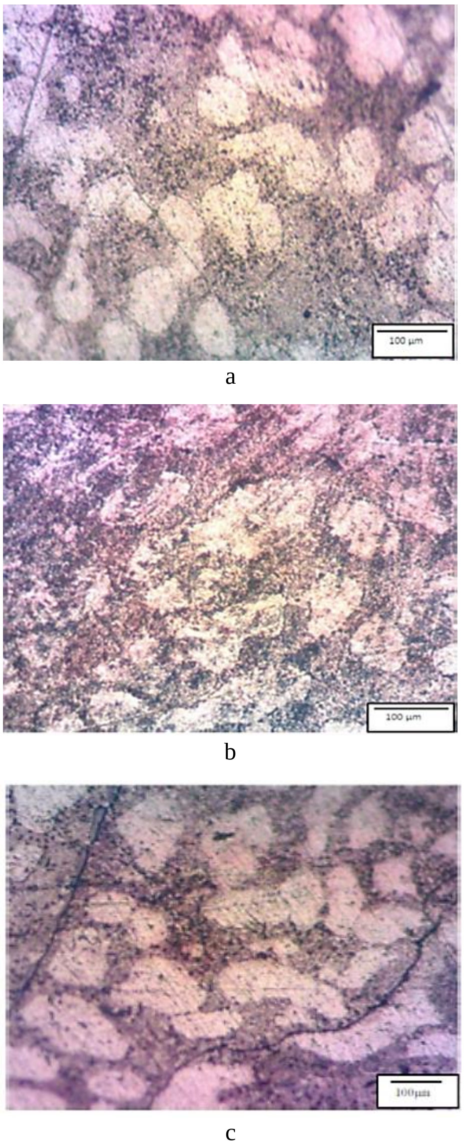


Figure 6 – The hardness of the samples

4.4 Microstructure analysis

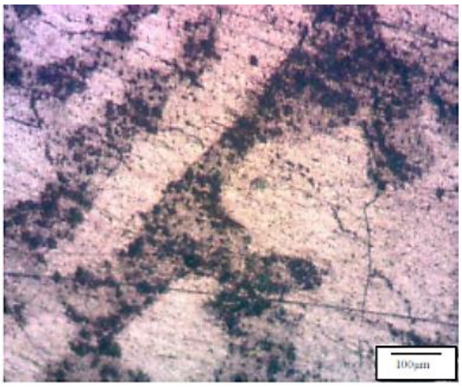
In the metallographic examination, the microstructure images of all extruded and non-extruded copper samples were examined at 100 µm, as depicted in Figure 7.



a

b

c



d

Figure 7 – Optical micrograph of non-extruded (a, c) and extruded (b, d) copper: a, b – 11.10 mm; c, d – 11.45 mm

The grains in non-extruded copper are relatively coarse and nonuniform with voids, but fine and relatively uniform grains are obtained in extruded copper. These coarse grains structures and voids are probably due to the slow cooling and formation of oxides at the interface during the deposition in sand casting. Also, the nonuniformity of the grain structure in non-extruded copper is due to the presence of silica during the sand casting.

Significant shear deformation in the particles is apparent compared to the microstructure before extrusion. The change in orientation of grains during and after extrusion would lead to a more homogeneous grain size than the copper before extrusion. The grains are refined during cold extrusion, and voids and dislocations are reduced significantly.

5 Conclusions

Scrapped copper coils were recycled through sand casting and subsequently subjected to cold extrusion in this research work. The extruded copper’s microstructural analysis, hardness, and tensile and compressive test were compared with the non-extruded copper. The following conclusions were deduced from the analysis.

The hardness of extruded copper of 11.10 mm and 11.45 mm improved significantly by 39 % and 41 %, respectively, compared with the respective non-extruded copper samples.

The compressive test reveals that the maximum load-bearing capacity, compressive strength, and breaking load of the extruded copper increases by 43 %, 41.6 %, and 94 %, respectively, compared with the non-extruded copper.

The tensile test indicates that the maximum load-bearing capacity, tensile strength, breaking load, and elongation of the extruded copper increase by 33 %, 22 %, 94 %, and 33 %, respectively, compared with non-extruded copper.

The micrograph reveals that grains in non-extruded copper are relatively coarse and nonuniform with voids, but fine and relatively uniform grains are obtained in extruded copper. The coarse grains are refined during cold extrusion, and voids and dislocations are reduced significantly. The limitation of this research is associated with the constructed extrusion machine that cannot withstand the extrusion of copper material that exceeds 11.45 mm. More research would be done to redesign the extrusion machine.

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