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Research Article

Mechanical Behavior and Wear Characteristics of a Conform Extruded C18150 (Cu-Cr-Zr Alloy) Rod

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The demand level of Cu-Cr base alloys is on the top notch from miniature parts to large parts based on their mechanical, metallurgical, chemical, and electrical properties. Due to these, the processing of Cu-Cr-Zr alloys for the betterment of those properties has been a prospect for researchers. Commonly, Cu-Cr alloys are manufactured through the conventional extrusion process at the industrial level. However, conventional extrusion processes have some limitations, specifically regarding grain size refinement and accompanying strength. To avoid such a problem, the conform extrusion process is inculcated for the Cu and Al alloys extrusion. In the present study, C18150 copper rods were extruded from the feed stock rod of 12.5 mm to 10 and 8 mm in diameter through the conform extrusion process; however, no posttreatment and artificial aging have been made to the extrudates. The extrudates of C18150 rods were tested mechanically and microstructurally. Significant mechanical properties improvement has been observed as the diameter decreased to a certain dimension. Same phenomenon is also observed in the microstructural and hardness case. Wear test results also followed the similarity with that of mechanical properties.

1. Introduction

There is a wide choice of materials, which exhibit infrequent in-use properties gained by controlling the phenomena occurring at the mesolevel, microsize, and nanoscale during manufacturing [1]. Cu-based alloys also behave in a similar manner in mesolevel, microsize, and nanoscale due to the effects of alloying and manufacturing techniques and their input processes parameters. Cu-Cr alloys are known for their great strength and good conductivity in electrical and thermal, super age hardenability, and corrosion resistance properties [2, 3]. In a copper matrix alloy, however, tensile strength and electrical conductivity properties are mutually exclusive and contradictory parameters need to be fulfilled by the alloy. In addition, the binary alloy of Cu-Cr displayed poor softening resistance at higher temperatures [4, 5]. These alloys with the abovementioned strength, however, do have certain applications in manufacturing industries as electrodes for resistance and spot welding, in nuclear fusion as heat sinker units [6], in transportation industry as network cable contactors in high-speed railway transportation [5, 7], and in electrical and electronics industries as IC lead frame. Chemical composition, deformation, and pre- and postheat treatment processes play a vital role in the mechanical, electrical, and other properties of Cu-based alloys [8]. One of the most commonly used methods for enhancing the basic properties is by adding alloy/s or element/s. Hence, by adding element, the properties of the Cu-Cr alloys were enhanced [9–13]. Among many elements, the Zr element is the appropriate alloying element added to the binary alloy of Cu-Cr alloy to improve its softening resistance at elevated temperatures of up to 500°C, mechanical strength, and electrical properties [14–17]. The recrystallization temperatures of Cu-Cr and Cu-Zr-Cr alloys were higher than that of pure copper due to the formation of fine precipitates during recrystallization [18]. Due to their appealing important characteristics, extensive research had been performed for further improvement in strength and softening resistance at elevated temperatures. In many alloys of Cu, Cu-Cr-Zr alloy showed betterment in terms of mechanical strength. The suitable working temperature of Cu-Cr-Zr alloy ranges from room temperature to 300°C, whereas by increasing the temperature, tensile strength decreased [19]. Thus, Cu-Cr-Zr alloys are an upgrade of Cu-Cr alloys that fulfilled the strength requirements through a precipitation strengthening mechanism by adding Zr [18, 20–23]. Therefore, Cu-Cr-Zr alloys are one of the most promising functional engineering materials to explore into industrial applications. Here are a few studies on severe plastic deformation and conform extrusion process discussed on Cu-Cr-Zr and Cu-Cr alloys. Feng et al. [24] extruded Cu-Cr-Zr rods continuously using the TLJ400 equipment. Comparison had been made with the microstructures, mechanical properties, and electrical conductivity of the alloys produced by the conform process with those by the conventional process. The experimental results showed that the grain size reduction obtained and improved the strength and ductility of the Cu-Cr-Zr alloy without a substantial decrease in electrical conductivity. Yuan et al. [25] investigated the microstructure evolution of Cu-0.2 Mg alloy during continuous extrusion in mass production. Recrystallized microstructures in the extruded parts showed that the predominant zones were the extending extrusion zone and extrusion rod zone. Feng et al. [26] welded Cu-Cr-Zr rods extruded using a continuous extrusion forming (CEF) process on the TLJ400 equipment. Then, they investigated the microstructures, mechanical properties, and electrical conductivity of the welds and the base material. The experimental results showed that after the CEF process, the grains were refined to the submicron scale through dynamic recrystallization, which improved the mechanical properties of the welding joint as well as the base material. Yuan et al. [27] investigated the microstructure evolution and properties of Cu-Cr-based alloys during continuous extrusion. The results showed that, initially, the hardness increased until reaching the maximum value in right angle bending and then decreased in the extending extrusion zone. Severe deformation and precipitation processes occurred during continuous extrusion. Sousa et al. [28] investigated the influence of equal channel angular pressing (ECAP) processing followed by aging heat treatment on the microstructure and mechanical and electrical properties of a Cu-Cr-Zr alloy. This ECAP produced a very refined microstructure with high dislocation density. The mechanical and electrical properties of the alloy were evaluated. The alloy got improvement both in mechanical strength and hardness as well as a sensible increase in electrical conductivity. An average smaller grain size and a higher dislocation density characterized the resulting microstructure. Laing et al. [29] evaluated the properties of a Cu-Cr-Ag alloy during continuous extrusion and aging process through microstructure. Xu et al. [30] carried out a similar kind of work. Shen et al. [31] studied the effects of CEF and subsequent aging treatment on the microstructure and electrical, mechanical, and tribological properties of Cu-1Cr-0.1Zr alloy. Results showed that the continuously extruded and subsequently peak-aged specimen had the best wear resistance, strength, and hardness. Bodyakova et al. [32] investigated the effect of severe plastic deformation by the conforming process of ECAE followed by cold rolling on the microstructures developed in a Cu-0.1Cr-0.1Zr alloy. From the results, it was shown that grain refinements and improvement in mechanical strength have been noted. The same phenomenon was also seen in Atefi et al. [33]'s research. From these research works, the significance level of Cu-Cr-Zr alloys conform extruded rods in industrial applications is clear. With this influence, the present study object is defined to investigate the mechanical, microstructural, and wear behavior of Cu-Cr-Zr alloy with the grade of C18150 under the influence of the continuous extrusion process (conform) parameters.

2. Material and Methodologies

The material used in the present investigation was an upcast feedstock of Cu-Cr-Zr alloy rod of C18150 grade. The upcast alloy rods with 31 m length and 12.5 mm diameter were loaded into a commercial setup of a continuous extrusion machine TBJ350. The deformation of the feedstock material was performed at an extrusion wheel velocity of six revolutions per minute (rpm) to extrude 10 mm and 8 mm diameter rods. The conform extrudates were then collected for testing and characterization without further heat treatment and artificial aging. The extrudates were also characterized in terms of microstructure, microhardness, tensile testing, and wear test. In the following sections, the detailed methodologies are stated for mechanical, microstructure, and wear tests.

2.1. Chemical Composition of C18150 Grade Alloy. The C18150 grade alloy specimen was tested for chemical composition by using the EDX analytical technique. From the EDX system results, Cr and Zr had been identified with the weight percentage of 0.52% and 0.90%, respectively, and the remaining is Cu (98.57%). Figure 1 shows the EDX spectrum of C18150, followed by the constituent elements and their weight percentages of them (Table 1).

2.2. Microstructure. The microstructure of C18150 was observed using an Olympus GX71 optical microscope. The standard procedure was followed such as cutoff, mounting, grinding, polishing, etching, and evaluation using the microscope. A specimen surface was ground with abrasive sheets with a reduction in the grain size as follows: P120 $\longrightarrow$ P320 $\longrightarrow$ P600 $\longrightarrow$ P1200. The specimens were then polished with velvet using a diamond abrasive emulsion. To reveal grain boundaries, the surface of microsections was etched chemically with copper no. 1 etchant (a solution of nitric acid in distilled water) and the samples were dipped for a period of 30–60 sec. For three C18150 rods of 8 mm, 10 mm, and 12.5 mm diameters, their microstructures were captured at 100x, 200x, and 400x magnifications. The specimens for microstructure and microhardness are shown in Figure 2.

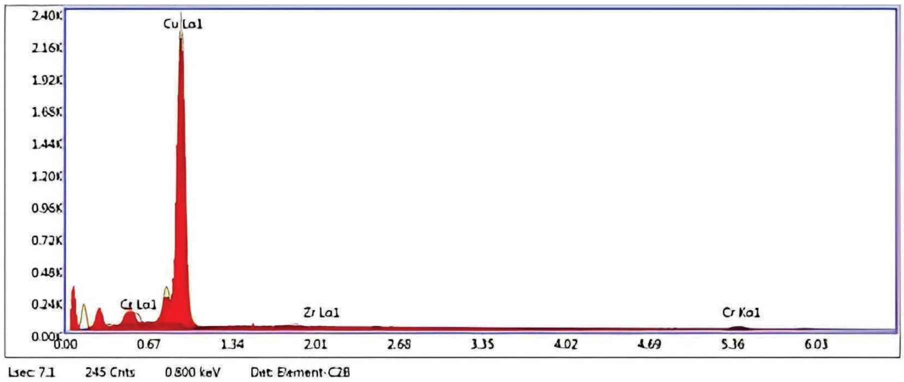


Figure 1: eZAF smart quant results.

Table 1: Constituent elements and their weight percentages of C18150.

Element	Weight (%)	Atomic weight (%)
Cu	98.57	98.79
Zr	0.91	0.78
Cr	0.52	0.43

Figure 2: Microstructure and microhardness specimens.

2.3. Microhardness. Samples of 12.5 mm diameter feedstock and 10 mm and 8 mm diameters of conform extrudate C18150 alloy rods were polished using different grades of emery paper to make the surface dents free before hardness testing. The micro-Vickers hardness testing machine was used for hardness testing. A 0.1 kgf load was applied with a dwell time of 10 sec for hardness measurements. The hardness was measured from the center to the surface of each rod as per ASTM E384. Three trials were made and an averaged hardness value was taken for analysis. Figure 3 shows the schematic representation of microhardness indent locations on the rods along the radial line during hardness measurement.

2.4. Tensile Testing of Cu-Cr-Zr (C18150). The mechanical properties of C18150 rods of 12.5 mm feedstock and 10 mm and 8 mm extrudates were measured using an MCS/UTE 20T tensile testing machine as per ASTM-E8M. Tensile tests were performed at a nominal cross-head speed of 2 mm/min at room temperature on the universal tensile testing machine and repeated twice for each set to check the reproducibility. Failure from grip or slippage during testing was not observed. Figures 4(a) and 4(b) show the tensile test samples as extruded and surface-machined samples. The mechanical properties of the specimen responses, such as "tensile strength," "yield strength," and "total elongations," were extracted.

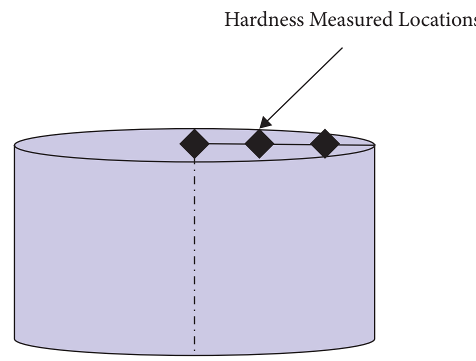


Figure 3: Schematic representation of the hardness measurement.

2.5. Wear Testing of C18150. Dry sliding wear tests were carried out on a pin-on-disc type machine of the model Ducom TR-201 apparatus, as shown in Figure 5. As per ASTM G99, the test specimens were prepared and tested. Two different types of wear parameters with speeds of 500, 600, and 700 rpm and loads of 20, 30, and 40 N were considered for the three rods (12.5 mm, 10 mm, and 8 mm), with a relative humidity of 70%. The parameters were arranged as per the L9 orthogonal array of Taguchi design as shown in Table 2 to minimize the number of experiments. The response variable considered is the specific wear rate.

The test samples are shown in Figure 6. The disk material used for the test was EN31 steel. After each experiment, the worn-out samples, the pin, and the disk faces were properly cleaned with acetone and weighed in the balance. Weight loss was measured with an electric sensor weighing machine. Wear was measured continuously with an electric sensor attached to the machine and was appropriately recorded.

3. Results and Discussion

The feedstock of 12.5 diameter and the conform extrudes of 10 mm and 8 mm diameters of C18150 rods were characterized through microstructure, microhardness, tensile, and

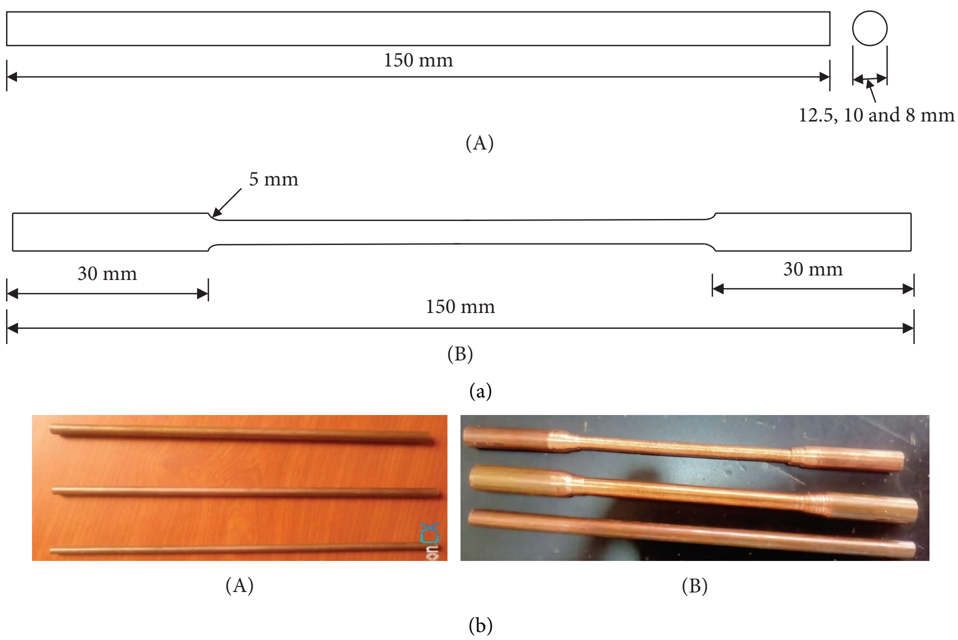


Figure 4: (a) Schematic representation of the tensile specimen of extruded and machined samples. (b) Tensile testing specimens of C18150 alloy.

Figure 5: Pin-on-disk testing setup.

Table 2: Levels of wear test performance parameters.

Process parameters	Level 1	Level 2	Level 3
Load (kN)	20	30	40
Speed (RPM)	500	600	700
Rod diameter (mm)	8	10	12

wear tests. Discussion on the test results and the causes for microstructural and mechanical property changes is presented in the following sections.

3.1. Microstructure. The microstructural analyses of the feedstock of 12.5 mm diameter and two conform extrudates of 10 mm and 8 mm diameters have been performed according to the aforementioned procedure. The microstructure images were taken at 100x, 200x, and 400x magnifications. The microstructures of the feedstock material are

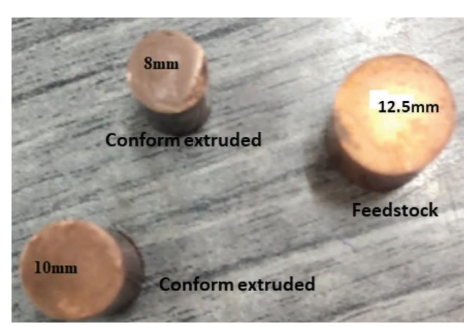


Figure 6: C18150 alloy rods of different diameters' surfaces before the wear test.

shown in Figure 7. Apparently, the grains have a cluster of Cr precipitates both inside the grains and at grain boundaries. The C18150 alloy has alloying elements of Zr and Cr, and the distribution of these alloys has been noted in the homogenous manner, as shown in Figure 8.

The nanosized precipitates distributed within the ultrafine grain matrix significantly improved strain hardening, as a consequence in the simultaneous improvement of uniform elongation, tensile strength, hardness, and wear resistance of the alloy without notably sacrificing the elongation to failure and electrical conductivity, due to the combined effect of grain refinement and precipitation. Moreover, clear grain structures with better uniformity have been observed in 10 mm diameter, as shown in Figure 9, with respect to the feedstock material. In addition, Cr and Zr distribution is uniform as per observations from the microstructure.

3.2. Hardness Testing. Vicker's hardness testing machine was used to measure hardness of C18150 samples as per ASTM-384. The hardness tests were performed to figure out the effect of the optimized input process parameters on the mechanical performance of the Cu-Cr-Zr alloy. The applied load, dwell time, and hardness test results of 8 mm, 10 mm, and 12.5 mm diameters of C18150 rods are shown in Figure 10. From Figure 10, it is possible to conclude that the extrusion ratio has a great effect on the hardness of the alloy. The hardness test results show that the highest hardness is for 8 mm diameter extrudates, followed by 10 mm and 12.5 mm extrudates. In all cases, the maximum hardness has been found near the surface of the rods. Among all the three samples, the 8 mm rod has shown more average hardness (134 ± 6VHN, 142.7 ± 5VHN, and 146.7 ± 5VHN, Table 3) in three zones as followed by 10 mm and 12.5 mm diameter rods. The variation in average hardness of each zone, i.e., from the center to the surface, is significant as expected from the conform extrusion process, and as the extrusion ratio decreases, more plastic deformation takes place. Of this, improvement in the strength of the product is inevitable.

The hardness of the alloy increases with the increase of the extrusion ratio, reaching the peak value of 146.7 ± 5VHN at the outer surface. This may be due to the dislocation density distribution from the continuous extraction process. In summary, the extrusion ratio does have a significant influence on the hardness of the Cu-Cr-Zr alloys.

3.3. Tensile Testing of Cu-Cr-Zr (C18150) Alloy. Tensile testing of C18150 rods of 12.5 mm, 10 mm, and 8 mm diameters was performed using the MCS/UTM 20T testing machine. Test specimens were made as per the ASTM-E8/E8M (in which the outer surfaces of feedstock and extrudates were machined) and another set was conform extruded. Figures 11 and 12 show illustrated tested tensile specimens on the UTM machine for the tensile properties. The failure mechanism is seen similar in as extruded and machines samples. Replication of the tensile tests has been done twice and their test results were recorded.

The mechanical properties of the tested samples of C18150 rods are discussed as follows. The maximum yield strength has been noted for 8 mm diameter as 498.5 ± 4 MPa, followed by 10 mm and 12.5 mm diameter rods with 485.5 ± 2 MPa and 468.7 ± 5 MPa, respectively, for machine specimens. The ultimate tensile strength (UTS) follows a similar trend, with 8 mm diameter having UTS of 523.2 ± 6 MPa, 10 mm diameter having 508.03 ± 6 MPa, and 12.5 mm diameter having 471.2 ± 2 MPa. It has been found that 8 mm diameter provides the highest elongation percentage of 19.86%, followed by 10 mm and 12.5 mm diameters at 15.88% and 13.97%, respectively. In the case of test samples of conform extruded ones (without machining of the outer layer of them), the maximum total elongation is also seen for 8 mm diameter as 21.8 and followed by 10 mm and 12.5 mm diameters with 18.0% and 13.8%, respectively. For ultimate tensile strength, an 8 mm diameter sample is noted maximum as 542 ± 7 MPa, followed by 10 mm and 12.5 mm diameter samples with 536.6 ± 4 MPa and 470.1 ± 4 MPa, respectively.

Similar observations were also observed for yield strength as 509.2 ± 6 MPa for 8 mm, 496.3 ± 3 MPa for 10 mm, and 449.2 ± 2 MPa for 12.5 mm diameters. The overall improved tensile behavior is seen for the 8 mm diameter extrudate sample, followed by 10 mm and 12.5 mm diameter rods, respectively. Such unusual mechanical behavior improvement is caused by the unique nanostructures generated through SPD processing, even distribution of zirconium element in the copper matrix, and precipitation hardening through the process. The combination of the ultrafine grain size and high-density dislocation pileups are the main causes for enhanced mechanical properties. High-density dislocations pileups also enable deformation by new mechanisms to improve material ductility. Both high strength and high ductility can be achieved by modifying the microstructures of metals and alloys through SPD. This finding also coincides with the microstructure and hardness values.

3.4. Wear Testing. The wear has been conducted as per the standard procedure on the pin on disc equipment for C18150 alloys of feedstock and extrudates with 12.5, 10, and 8 mm diameters. Figure 13 shows the surfaces of the C18150 alloy rods of 12.5, 10, and 8 mm after the wear test. Test results have been noted in terms of mass loss at different loading conditions and speed variations (Table 4).

The experiment results showed that the load and the speed affect the wear rate of the alloy. The results also indicate that the wear rate (weight loss) has been increased by the increasing load and increasing sliding distance.

Overall, it is clear from microstructures, hardness tests, tensile tests, and wear tests that the extruded rod of 8 mm diameter has shown the best performance compared to 10 and 12.5 mm diameter rods. The wear tests from the other works stated that Cu-Cr-Zr alloy wear behavior was dependent on its strength and hardness [34].

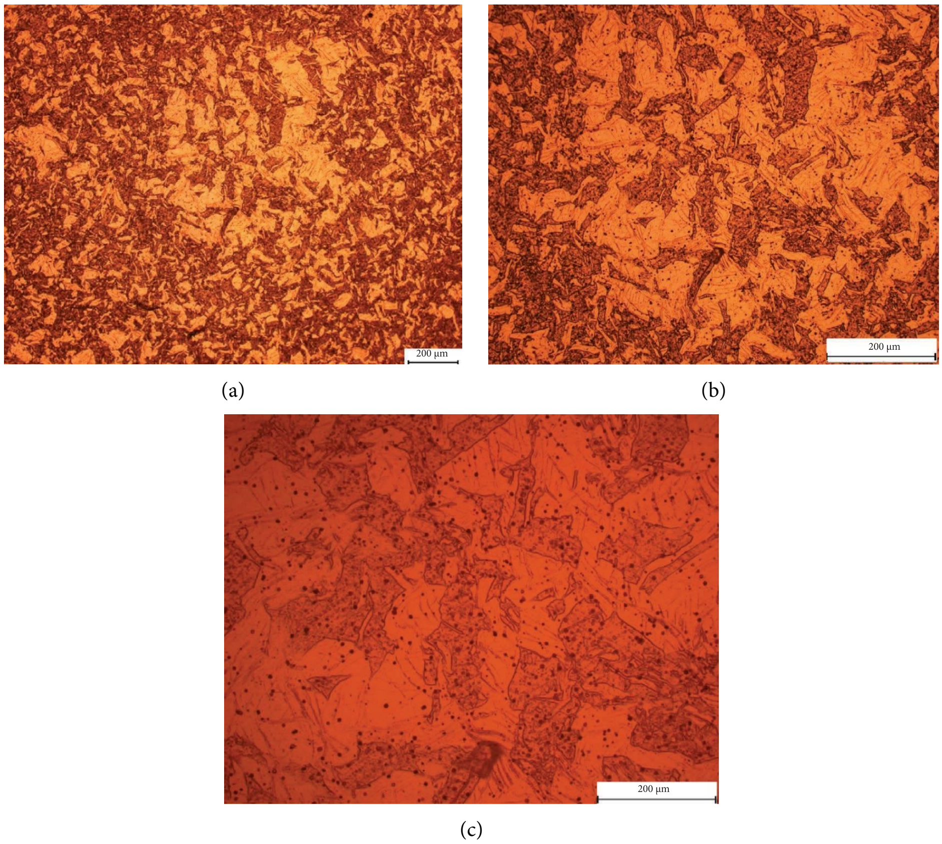


Figure 7: Microstructures of the 12.5 mm diameter feedstock material at three magnifications: (a) 100x. (b) 200x. (c) 400x.

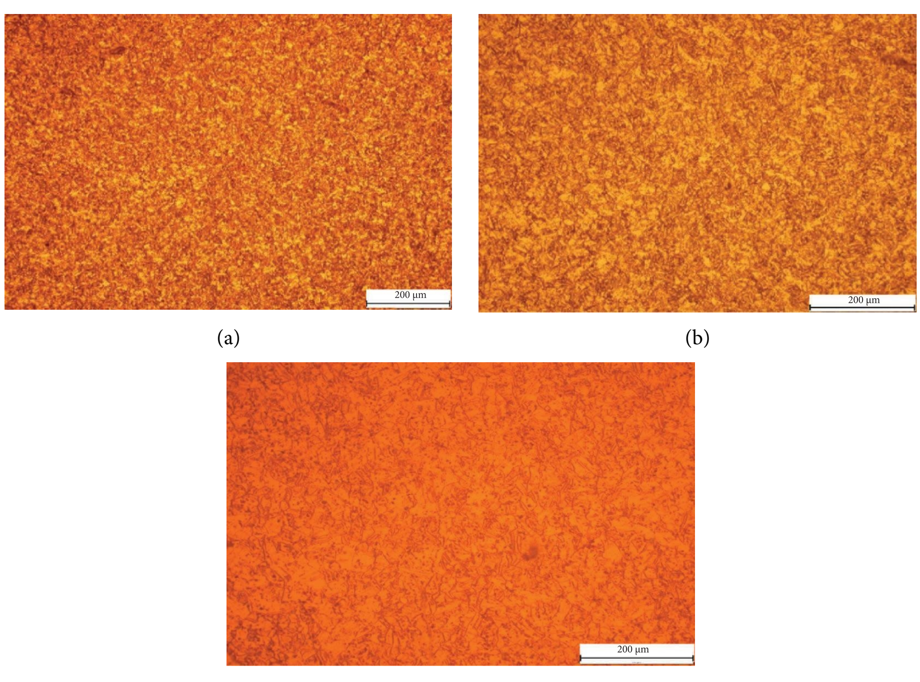
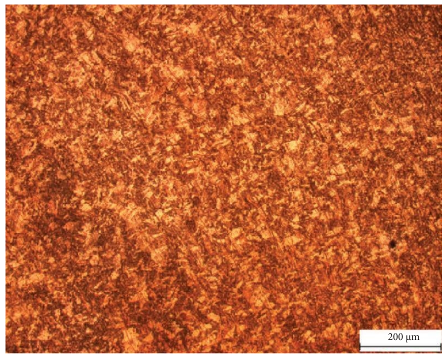
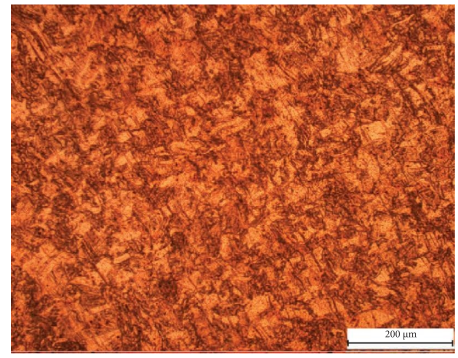


Figure 8: Microstructures of conform extruded rods of 8 mm diameter at three magnifications: (a) 100x. (b) 200x. (c) 400x.



(a)



(b)

(c)

FIGURE 9: Microstructures of conform extruded rods of 10 mm diameter at three magnifications: (a) 100x. (b) 200x. (c) 400x.

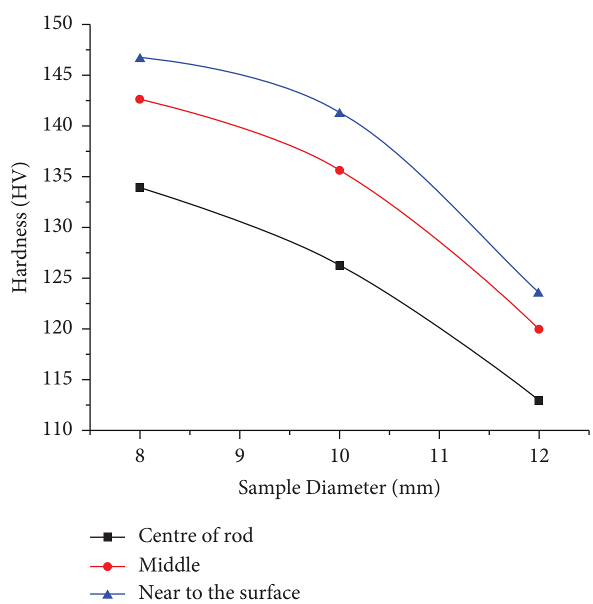


FIGURE 10: Hardness of C18150 rods.

Table 3: Hardness of C18150 alloy rods.

Diameter of rods		Load applied (kgf)	Dwell time (sec)	Micro hardness center	Micro hardness Middle	Micro hardness Near to surface
8 mm	Replication 1	HV0.1	10	130	138	142
	Replication 2			142	149	152
	Replication 3			130	141	146
Average				134 ± 6	142.7 ± 5	146.7 ± 5
10 mm	Replication 1			122	132	140
	Replication 2			125	136	145
	Replication 3			132	139	139
Average				126.3 ± 4	135.7 ± 4	141.3 ± 4
12.5 mm	Replication 1			112	120	123
	Replication 2			114	120	124
	Replication 3			115	122	126
Average				113.7 ± 2	120.7 ± 2	124.3 ± 2

Figure 11: Tensile tested samples failure mechanism (as extruded).

Figure 12: Tensile tested samples failure pattern (outer surface of extrudates machined).

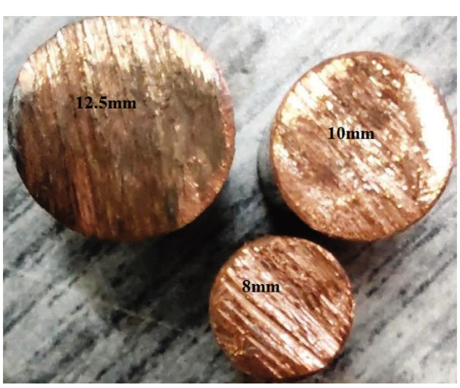


Figure 13: C18150 surfaces after wear testing.

Table 4: Wear test results.

S. nos.	Sample	Load (N)	Speed (rpm)	Mass before (g)	Mass after (g)
1	8	20	500	18.010	18.000
2	8	30	600	18.000	17.990
3	8	40	700	17.990	17.960
4	10	20	600	30.250	30.250
5	10	30	700	30.250	30.240
6	10	40	500	30.240	30.230
7	12	20	700	30.540	30.540
8	12	30	500	30.540	30.530
9	12	40	600	30.530	30.510

4. Conclusion

The following conclusions are drawn from the present work on conform extruded C18150 alloys through microstructures, microhardness tensile tests, and wear tests.

(i) From the microstructure analysis, gain sizes are refined as the extrusion ratio increases from 12.5 mm to 10 and 8 mm. It indicates that during the conform extraction process, grain size refinement is expected. All the feedstock materials experience severe plastic deformation during conform extrusion.

(ii) In case of mechanical behavior, the machined tensile specimen of 8 mm diameter has maximum yield strength of 498.5 ± 4 MPa compared to 10 and 12.5 mm diameters (485.5 ± 2 MPa and 448.7 ± 5 MPa, respectively). For ultimate tensile strength case, 523.2 ± 6 MPa as a maximum for 8 mm diameter and followed by 10 and 12.5 mm diameter with 508.03 ± 6 MPa and 471.2 ± 2 MPa, respectively, whereas total elongation was the maximum for 8 mm diameter with 19.86%, followed by 10 mm and 12.5 mm diameters with 15.88% and 13.97%, respectively.

(iii) For as-extruded samples, the maximum percentage of elongation is for 8 mm diameter with 21.8%, followed by 10 mm and 12.5 mm diameters with 18.0% and 13.8%, respectively. Among the UTS results, the 8 mm diameter sample is noted as the maximum with 542 ± 7 MPa, followed by 10 mm and 12.5 mm diameter samples with 536.6 ± 4 MPa and 470.6 ± 4 MPa, respectively. As a whole, highest tensile behavior has been noted for the 8 mm diameter, followed by 10 mm and 12.5 mm diameter rods. It coincides with the microstructure and hardness values too.

(iv) In the case of wear tests, load and speed do have significant effects on mass loss. Generally, the wear volume increases linearly with an increase in load, and the wear volume increases very slightly with an increase in speed. There is also a linear relationship between abrasive wear resistance and hardness results.

(v) From this work, the significance of the severe plastic deformation process like the conform extrusion process has been seen, which proved for the improvement of mechanical properties. In addition, from this work, output research works across the globe can understand the process influence on the product properties under various parameters and can estimate the upcoming material deformation phenomenon.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical Approval

All procedures performed in studies were in accordance with the ethical standards of the institutional and/or national research committee and with the comparable ethical standards.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Tariku Desta investigated and executed the entire objective of the work using proper research methodology. Devedra K. Sinha executed the research as per the scientific principles. Perumalla Janaki Ramulu was responsible for topic selection, supervising, and executing the research as per the scientific principles. Every author has made significant contribution towards the successful completion of the research work associated with the manuscript.

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