CHAPTER 5

EXPERIMENTAL STUDY, VALIDATION AND CHARACTERIZATION

5.1 INTRODUCTION

Continuous Extrusion setup is used to carry out experiments for different metals and alloys in this chapter. The results so obtained would be required to be validated to ensure the correctness of the theory (simulations) and practice (experiments).

In the continuous extrusion set up, extrusion ratio, extrusion wheel velocity and locking pressure by intensifier can be set and calculated for the best condition of extrusion of the alloy so that a defect free part is produced. An experimental validation of the experimental result is performed for Pure Aluminum and Pure Copper rod and it is found that a good agreement is obtained using CAE simulation. Material characterization of the product samples such as microstructure analysis, tensile test and hardness test before and after deformation has been carried out for the test samples to predict the material properties of the feedstock.

5.2 EXPERIMENTAL TESTS

Several experiments are done using the proposed setup. Defects possible with the fabricated set up are internal cracking, piping and surface cracking due to high temperature and high extrusion speed. These probable defects are considered for analyzing the scope of the setup fabricated.

The commercial continuous extrusion setup (Figure 5.1) having specification (Table 5.1) and the fabricated Continuous Extrusion setup (Figure 5.2) having specification (Table 5.2) has been used for testing of different metals and alloys (Aluminum Al 1100, and Copper C 101).

Table 5.1: Specification of Commercial Setup (Setup 1)

S. No.	Parameters	Values	Applications
1	Bed Length	5 meters	Setup is applicable for extrusion of Copper (C 101) round rods, square rods, tubes and bus bars with wide range of extrusion ratio.
2	Weight	5 ton	
3	Motor Power	110 kW	
4	Extrusion wheel Diameter	300 mm	
5	Feedstock Diameter	12.5 mm	

Table 5.2: Specification of fabricated Setup (Setup 2)

S. No.	Parameters	Values	Applications
1	Bed Length	3 meters	Setup is applicable for extrusion of Aluminum (AA1100) round rods with wide range of extrusion ratio.
2	Weight	3 ton	
3	Motor Power	45 kW	
4	Extrusion wheel Diameter	300 mm	
5	Feedstock Diameter	9.5 mm	

The main assumptions of the fabricated setup are: (i) very low vibration, (ii) appropriate rigidity, (iii) positive drive of the gearbox, gears, extrusion wheel and coining wheel. Capability of the set up depends on the size of the feedstock and extrusion wheel speed.

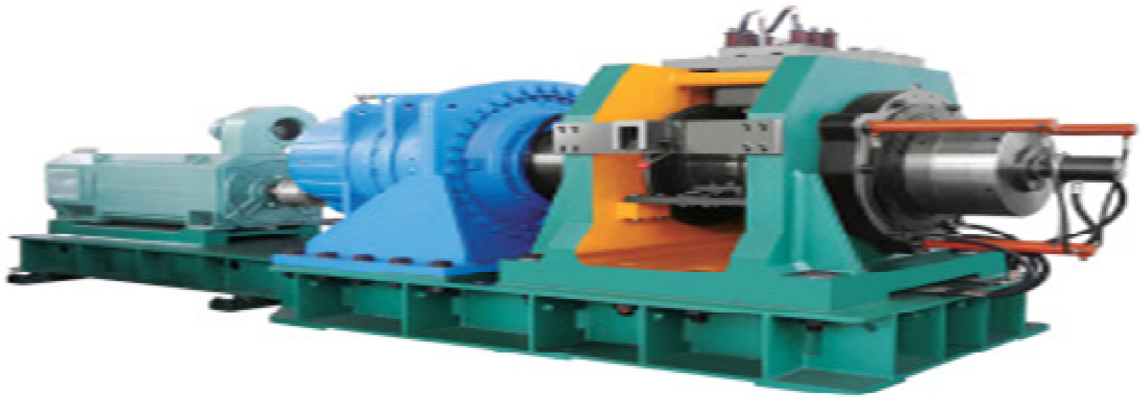


Figure 5.1: Commercial Continuous Extrusion setup 1[Internet Resource 2]

Figure 5.2: Fabricated Continuous Extrusion setup 2 (9.5 mm Aluminum feedstock material)

Experimental plans

There are two main factors to be studied with respect to their interdependencies while products are formed and therefore plan of the experiments need to be designed in such a way that if one parameter is changed, the effect of other parameters remains constant. The parameters varied are given below:

1. Changing the extrusion wheel RPM

   (Four variation: 4, 6, 8, 10) RPM for Aluminum on setup 2 (fabricated) and (4, 6, 8, 10) RPM for Copper on setup 1 (commercial).

2. Changing the extrusion ratio

   (Three variation: 2.5, 1.84, 1.41) for Aluminum on setup 2 and (4.34, 3.18) for Copper on setup 1.

Initial Experiments

Tests are carried out with free runs on the setup so as to check the functionality of the setup and also to see the deformation behavior of different material under loading. The main aim of the experiment is to extrude a work piece. Figures 5.3 and 5.4 shows the extruded product of Aluminum and Copper feedstock on setup 2 &1 respectively.

Figure 5.3: Extruded product of Copper alloy (Setup 1)

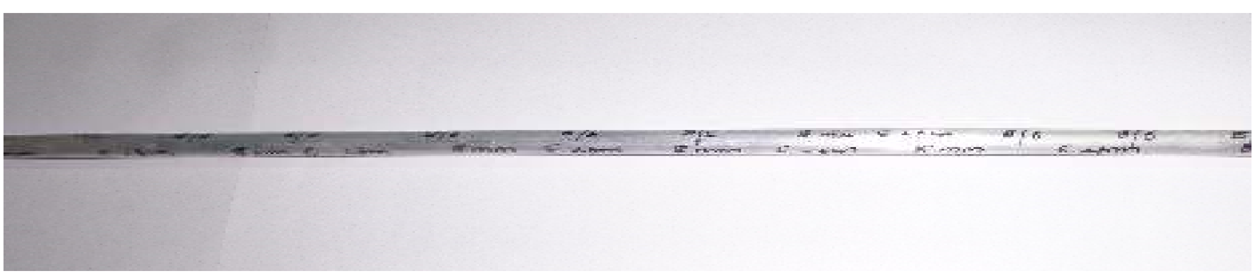


Figure 5.4: Extruded product of Aluminum alloy (Setup 2)

Experiments: (Aluminum alloy Al 1100) on setup 2.

Several experiments on Aluminum alloy Al 1100 are performed and have been found to be very successful as its deformation behavior is appropriate under process parameters of the setup as extrusion wheel (RPM) and extrusion ratio. For various RPM of the extrusion wheel and extrusion ratio, extrusion of Aluminum alloy is carried out and Figures have been plotted to show the results of experimentation. Table 5.3 shows element composition of the feedstock used for experimentation. Table 5.4 and Table 5.5 shows the results of experiments carried out and validation of the results for Aluminum alloy respectively. Figures 5.5 to 5.7 show the Aluminum rod before and after extrusion at different wheel velocity and extrusion ratio.

Table 5.3: Composition of the feedstock used

Elements	% Composition
Si	0.2 to 0.6
Fe	0.0to 0.35
Cu	0.0 to 0.1
Mn	0.0 to 0.1
Mg	0.45 to 0.9
Zn	0.0 to 0.1
Ti	0.0 to 0.1
Cr	0.1 max
Al	Balance (99.25 to 97.75)

Figure 5.5: Extruded product of Aluminum alloy (6 mm diameter at 6 RPM, extrusion ratio 2.5) on setup 2

Figure 5.6: Extruded product of Aluminum alloy of (7 mm diameter at 6 RPM, extrusion ratio 1.84) on setup 1

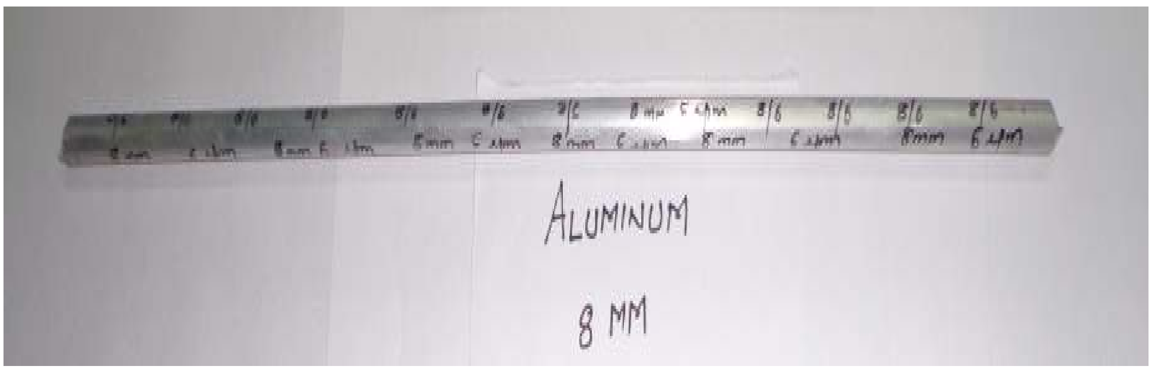


Figure 5.7: Extruded product of (8 mm diameter at 6 RPM, extrusion ratio 1.41) on setup 2

Table 5.4: Results of experiments for Aluminum alloy on setup 2

Sample No.	Shape	Extruded rod diameter (mm)	Extrusion Ratio	RPM	P	I	V	Total Power (kW)
1	Circular	6	2.5	4	25.6	86	220	18.92
				6	25.4	84	220	18.48
				8	25.2	80	220	17.6
				10	25	77	220	16.94
2		7	1.84	4	25.5	83	220	18.26
				6	25.5	79	220	17.38
				8	25.5	76	220	16.72
				10	25.5	74.6	220	16.41
3		8	1.41	4	25.6	80	220	17.6
				6	25.6	78	220	17.16
				8	25.6	74	220	16.28
				10	25.6	73	220	16.06

In above Table 5.4, **P**: Pressure in MPa, **I**: Current in Amperes, **V**: Voltage in Volts

Table 5.5: Validation (Aluminum alloy)

Parameters	Simulation Result Simulation Power (kW)	Experimental Result Experimental Power (kW)	% Error (Between Simulation & Experiment)
Feedstock Diameter=9.5mm, Extruded Rod diameter=6mm, RPM of Extrusion wheel=8, Extrusion ratio=2.5	16.53	17.6	6.47
Feedstock Diameter=9.5mm, Extruded Rod diameter=7mm, RPM Extrusion wheel=8, Extrusion ratio=1.84	16.79	16.72	0.42
Feedstock Diameter=9.5mm, Extruded Rod diameter=8mm, RPM Extrusion wheel=8, Extrusion ratio=1.41	14.9	16.2	8.72

Experiments: (Pure Copper Feedstock) on Setup 1

The experiment is done for the Copper feedstock for several extrusion wheel speed and extrusion ratio and formability of Copper has been found very well after the experiments. Figures 5.8-5.10 shows the extruded product of Copper at different wheel velocity and extrusion ratio. Figure 5.1 show the commercial setup used for carrying out the experimentation of Copper feedstock at different wheel velocity and extrusion ratio. Table 5.6 represents the chemical composition of Copper feedstock used for carrying out experimental study. Table 5.7 and 5.8 shows the results of experimentation and validation of results obtained for copper feedstock material on commercial setup.

Table 5.6: Chemical Composition of the Copper feedstock (C 101) used for extrusion experiments

Elements	% Composition
Copper	99.99
Oxygen	0.0005

Figure 5.8: Pure Copper rod feedstock before extrusion (12.5 mm diameter)

Figure 5.9: Extruded Copper product (6 mm diameter at 6RPM, extrusion ratio 4.34)

Figure 5.10: Extruded Copper rod (7mm diameter at 6 RPM, extrusion ratio 3.18)

Table 5.7: Results of experiments for Copper feedstock on setup 1

S. No.	Shape	Extruded Rod diameter (mm)	Extrusion Ratio	RPM	Pressure (MPa)	Voltage (Volts)	Current (Ampere)	Power= V*I (kW)
1	Circular	6	4.34	4	24	440	133.7	58.8
				6	25.2	440	133.5	58.6
				8	24.9	440	132.4	58.2
				10	24.6	440	132	58.0
2	Circular	7	3.18	4	23.5	440	129.8	57
				6	25.7	440	128	56.32
				8	25.4	440	126	55.4
				10	24.8	440	125	55

Table 5.8: Validation of results for Copper feedstock

Parameters	Analytical Result (Analytical Power) (kW)	Simulation Result Simulation Power (kW)	Experimental Result Experimental Power (kW)	% Error (Between Simulation and Experiment)
Feedstock Diameter=12.5mm, Extruded Rod diameter=6mm, RPM Extrusion wheel=8, Extrusion ratio=4.34	64.75	58	58.2	0.4
Feedstock Diameter=12.5mm, Extruded Rod diameter=7mm, RPM Extrusion wheel=8, Extrusion ratio=3.18	64	55	55.4	0.8

5.3 Parametric study of Continuous Extrusion process (Comparison between experimental and simulation results for Aluminum alloy

Figure 5.11 - 5.14 shows the graphical comparison of experimental and simulation results for Aluminum feedstock material.

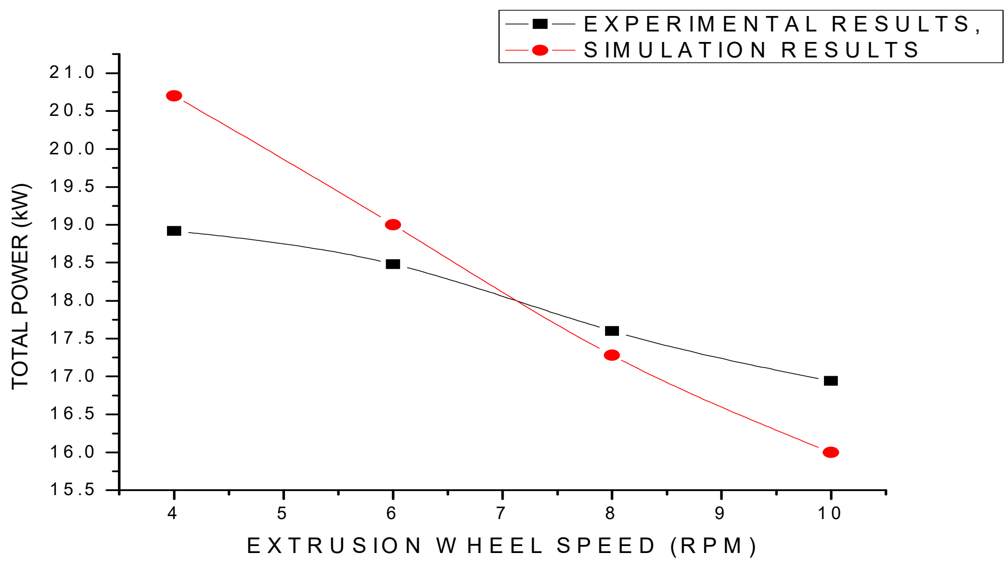


Figure 5.11: Graphical comparison of experimental and simulation results (effect of wheel speed on total power required for extrusion of Aluminum alloy for 6 mm diameter)

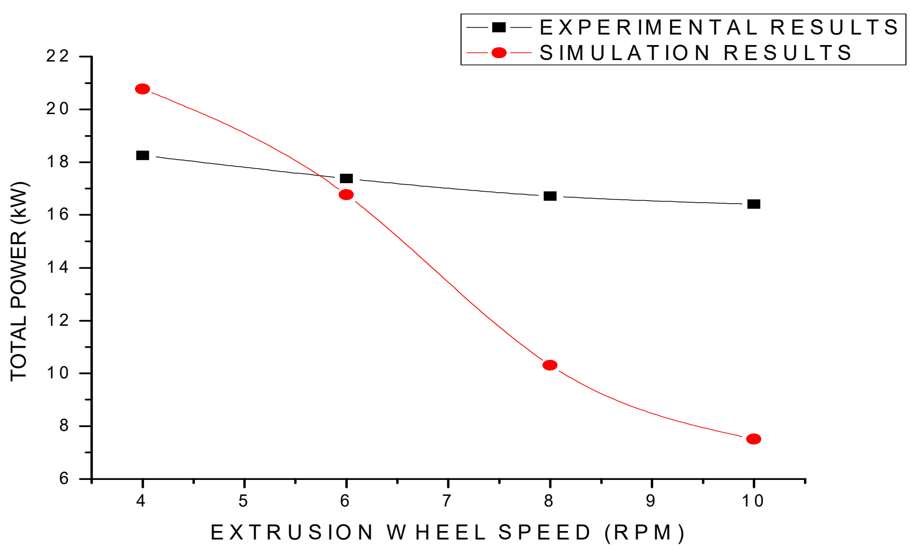


Figure 5.12: Graphical comparison of experimental and simulation results (effect of wheel speed on total power required for extrusion of Aluminum alloy for 7 mm diameter)

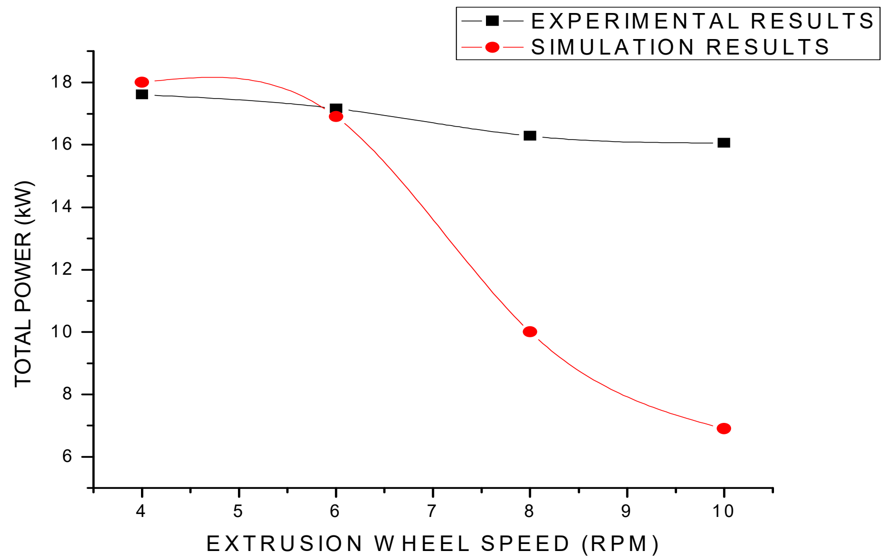


Figure 5.13: Graphical comparison of experimental and simulation results (effect of wheel speed on total power required for extrusion of Aluminum alloy for 8 mm diameter)

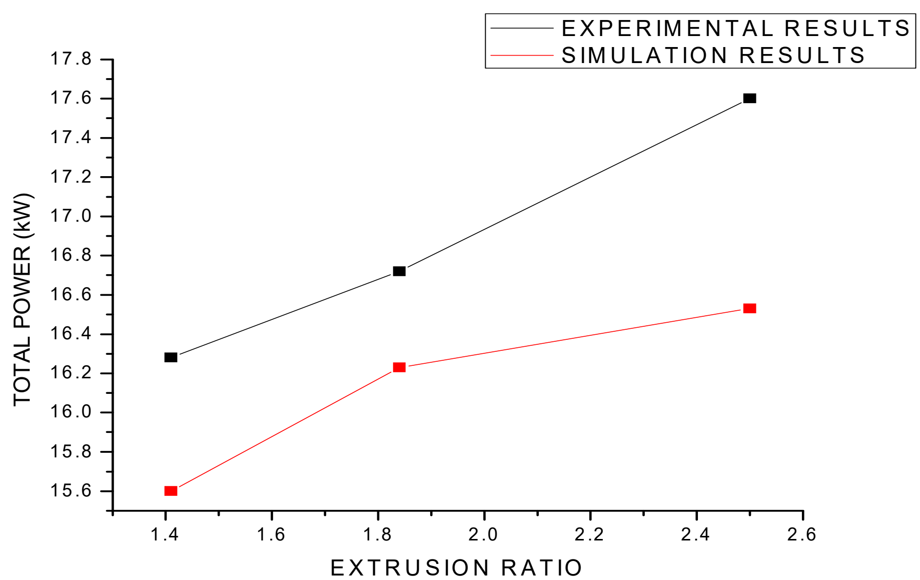


Figure 5.14: Graphical comparison of experimental and simulation results (effect of extrusion ratio on total power required for extrusion of Aluminum alloy for 8 RPM wheel speed)

5.4 Parametric study of Continuous Extrusion process (Comparison between experimental and simulation results for Copper alloy

Figure 5.15 show the graphical comparison of experimental and simulation results for copper feedstock material.

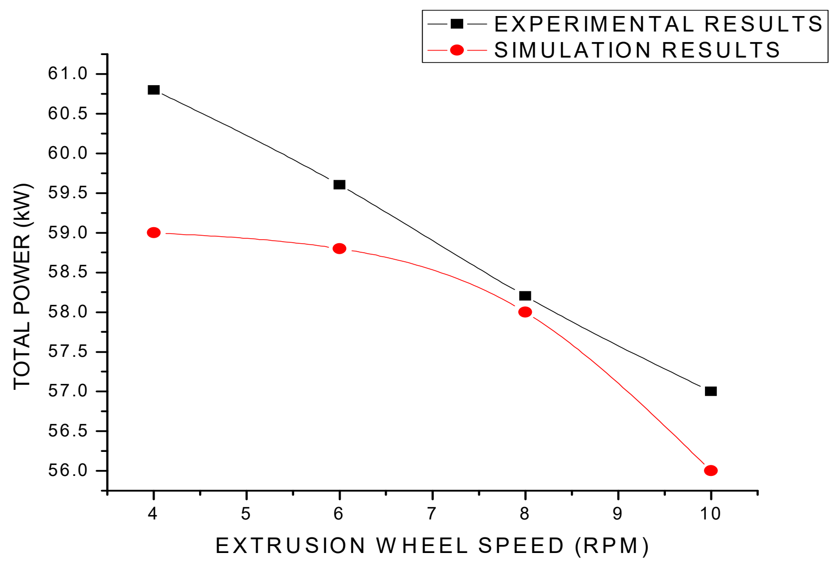


Figure 5.15: Graphical comparison of experimental and simulation results (effect of wheel speed on total power required for extrusion of Copper alloy for extrusion ratio of 4.34)

5.5 Characterization

In this section three more studies are introduced such as Microstructure analysis of the extruded products like Copper and Aluminum, Tensile test and Hardness test of the extruded products to examine the material properties and microstructure prior and after the deformation of the feedstock material. The main aim of the material characterization is to determine the material properties of initial feedstock material and of the extruded product before and after extrusion. Microstructural examination reveals the possible grain refinement of the feedstock material.

Microstructure analysis of the raw material and extruded product

In this section, the process of microstructure analysis of the extruded products through LOM (Light Optical Microscopy) method is used .The Continuous Extrusion of

Aluminum and Copper rod is carried out on the designed and fabricated (setup 2) and on commercially available Continuous Extrusion (set up 1) respectively.

Metallography (Sample Preparation) of Samples

The products of Aluminum and Copper extruded out using the modified and fabricated setup and commercially available setup are cut to a finite length using hacksaw as shown in Fig 5.16 and 5.17. Also samples of raw feedstock of Aluminum and Copper are prepared to study the microstructure of the material before and after deformation. The aim of this section is to determine the probable extrusion wheel speed and extrusion ratio at which the best microstructures are obtained.

Figure 5.16: Microstructure samples of Aluminum rod before and after extrusion

Figure 5.17: Microstructure samples of Copper rod before and after extrusion

For microstructure analysis of any material, the faces of prepared samples on which microstructures is to be obtained are initially rubbed on emery papers of coarse, medium and fine grades in longitudinal and lateral directions so as to avoid any scratches and obtain mirror like faces before polishing of the samples. Polishing of the samples plays a vital role in the microstructure analysis of different materials. Some materials which are very soft such as Aluminum are very sensitive to pressure, therefore polishing of such kind of materials consumes much time as compared to other materials such as Copper and Brass. Polishing of the prepared samples are carried out till scratch free mirror like finish of the faces of the prepared samples are obtained. Velvet cloth, Brasso and Kerosene have been used while polishing of the prepared samples. During polishing of the prepared samples it has been found that polishing of Copper is easier as compared to the polishing of Aluminum samples. After polishing, the samples are etched using proper etchant. For Aluminum samples, Keller's reagent (3 ml HCl, 5 ml HNO_3, 2 ml HF, 190 ml water) has been used as etchant whereas for Copper samples Ferric chloride in suspension of hydro fluoric acid and water has been used as etchant. Finally, the polished scratch free samples are mounted on the slide and are placed under the microscope with different magnifications for obtaining microstructures of the prepared samples.

Microstructure analysis of samples

Different samples of Aluminum and Copper at various extrusion wheel velocity and extrusion ratio have been taken to study the microstructure and deformation characteristics. Measurement of grain size and its comparison before and after deformation (extrusion) is possible by using standard length at different places in an image and the equation is given as [Underwood et al., (1970)]:

$d= (L_{average}.\text{grain shape factor})/M$

Where d: grain diameter, and

M: magnification

and grain shape factor is constant for every material .Therefore its value can be neglected for comparison before and after deformation (extrusion).

$L(ave)= 1/N\sum L/ni$

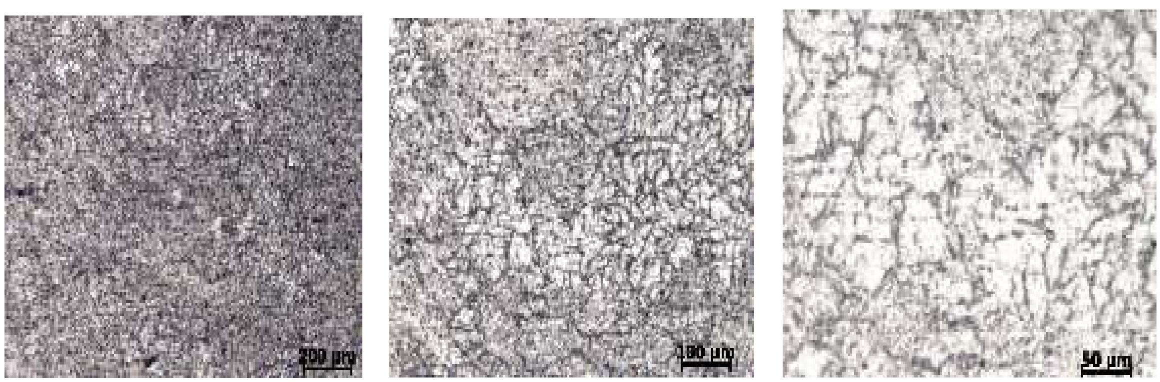
N: number of data

L: Real visible and measured test length and

n_i: number of intercept.

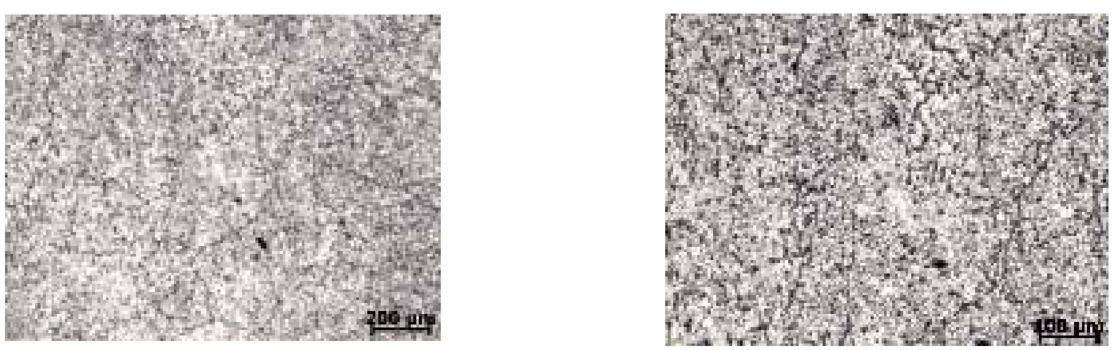
For all images real magnification has been calculated from the ratio of visible or actual standard length over written length. All the samples are of circular shape cut out of raw feedstock's as well as of extruded products. The samples of Aluminum and Copper are prepared from the extruded product at various extrusion wheel velocity and extrusion ratio. Sample of raw feedstock is also prepared to examine its microstructure before deformation (extrusion) and comparison of microstructure and grain size can be studied at different extrusion wheel velocity and extrusion ratio. LOM (Light Optical Microscope) has been used for getting images of microstructure after proper polishing. Magnification of 50x, 100x and 200x has been used for all the samples.PL-Ink capture and Axiovision Rel 4.8 software have been used for obtaining the images under microscope and for measuring the grain size by making standard length respectively.

In this section the microstructure images of all the samples of Aluminum alloy Al 1100 has been carried out under different extrusion wheel velocity and extrusion ratio. The microstructure of the feedstock before extrusion and the final microstructure of the extrudate under different extrusion wheel velocities and extrusion ratios are shown in figures. The microstructure images of all the samples show no considerable changes of grain size during before deformation (extrusion) but the shape of grains is changed as they are elongated after deformation (extrusion). The feedstock before continuous extrusion has uniform grains. The average size of the extruded alloy under extrusion wheel velocity ranging from 6 to 8 RPM ranges from 80μ to 200 μ.It is seen that under extrusion wheel velocities of 6 and 8 RPM the grain structures are larger and inhomogeneous. Under the extrusion wheel velocity of 10 RPM, the structure containing fine and uniform grains are obtained. A further increase in wheel velocity to 18 RPM slightly increases the grain size. Figures 5.18-5.25 show microstructures of Aluminum samples at various wheel velocities and extrusion ratio are shown below.



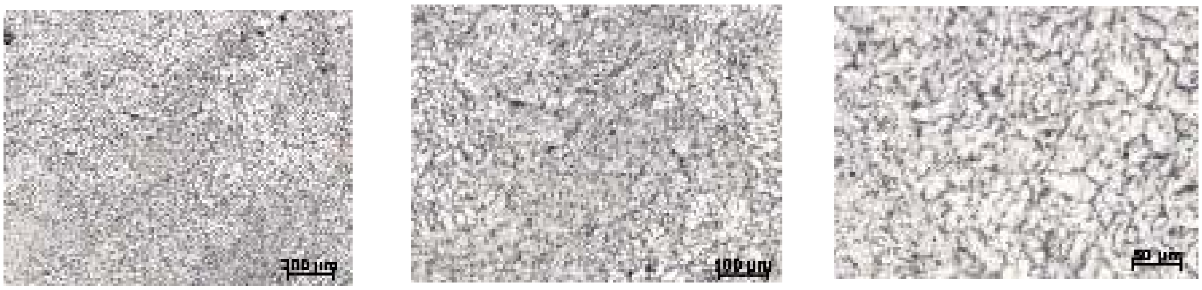
(a) **(b)** **(c)**

Figure 5.18: (a), (b), (c) shows the microstructures of Aluminum samples of 6mm size at 6 RPM at 50x, 100x and 200x respectively



(a) (b)

Figure 5.19 : (a) and (b) shows the microstructures of Aluminum samples of 7mm size at 6RPM at 50x, 100x and 200x respectively

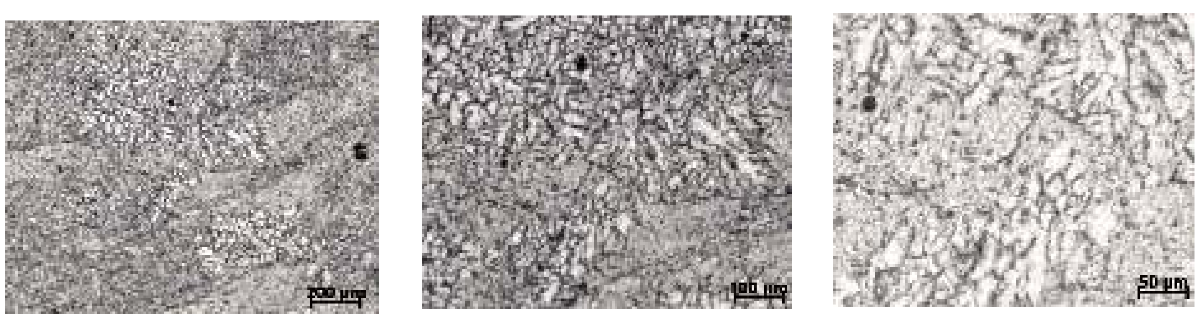


(a) **(b)** **(c)**

Figure 5.20 :(a), (b), (c) shows the microstructures of Aluminum samples of 8mm size at 6RPM at 50x, 100x and 200x respectively

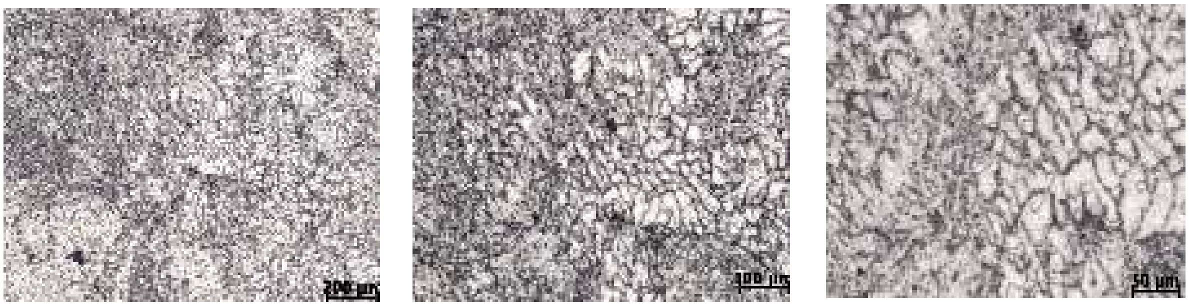
(a) **(b)** **(c)**

Figure 5.21:(a), (b), (c) shows the microstructures of Aluminum samples of 6mm size at 8RPM at 50x, 100x and 200x respectively



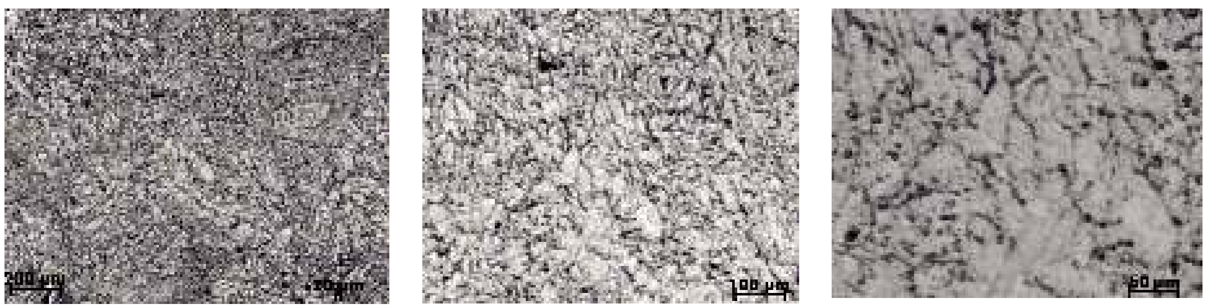
(a) **(b)** **(c)**

Figure 5.22:(a),(b), (c) shows the microstructures of Aluminum samples of 7 mm size at 8 RPM at 50x, 100x and 200x respectively



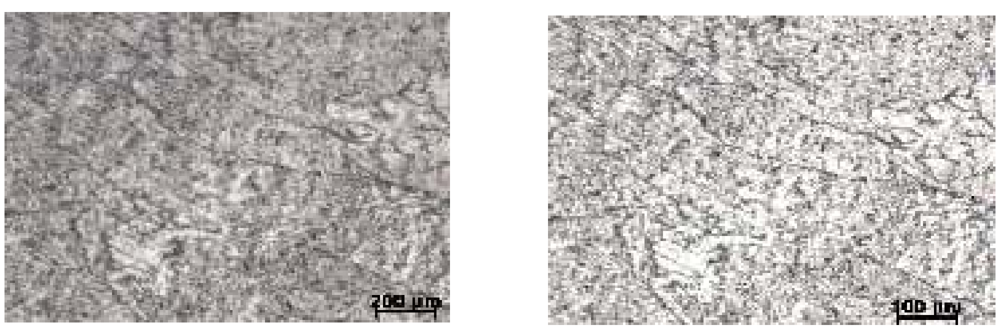
(a) **(b)** **(c)**

Figure 5.23: (a), (b), (c) shows the microstructures of Aluminum samples of 8 mm size at 8 RPM at 50x, 100x and 200x respectively



(a) **(b)** **(c)**

Figure 5.24: (a), (b), (c) shows the microstructures of Aluminum samples of 8 mm size at 10 RPM at 50x, 100x and 200x respectively

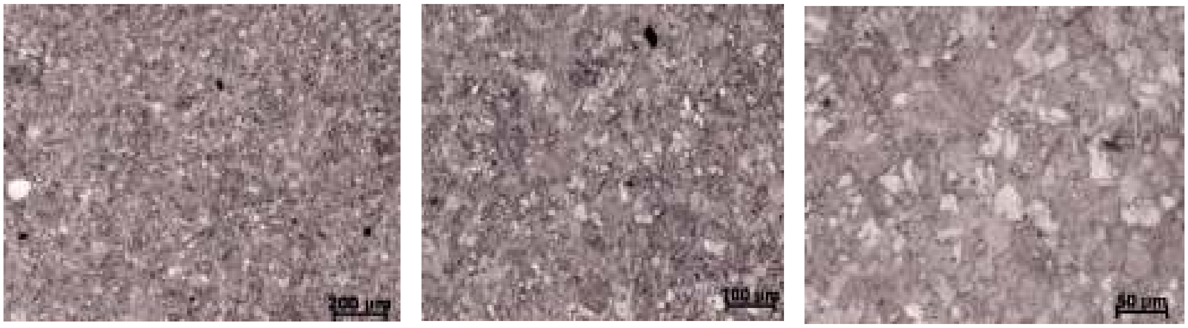


(a) (b)

Figure 5.25: (a) and (b) shows the microstructures of Aluminum samples of raw feedstock of 9.5 mm size at 6 RPM at 50x and 100x respectively

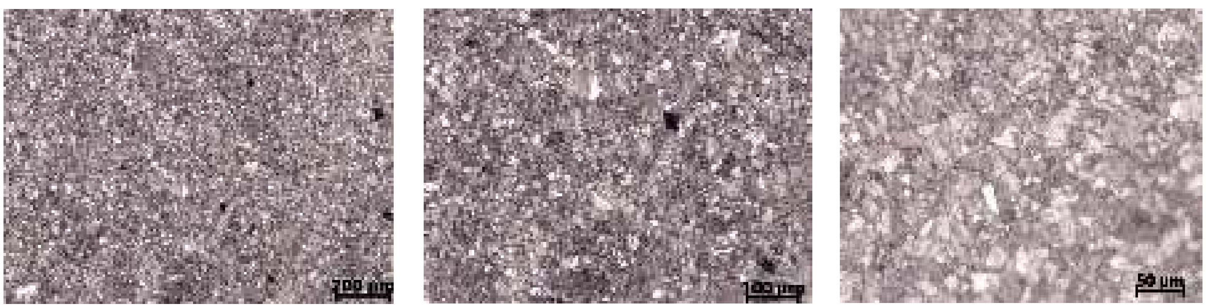
5.6 Microstructure analysis of Copper (C 101) samples

In this section the microstructure images of all the samples of Copper alloy C 101 has been carried out under different extrusion wheel velocity and extrusion ratio. The microstructure of the feedstock before extrusion and the final microstructure of the extrudate under different extrusion wheel velocities and extrusion ratios are shown in Figures 5.26 to 5.34. The microstructure images of all the samples show no considerable changes of grain size during before deformation (extrusion) but the shape of grains is changed as they are elongated after deformation (extrusion). The feedstock before continuous extrusion has uniform grains. The average size of the extruded alloy under extrusion wheel velocity ranging from 6 to 8 RPM ranges from 80μ to 200 μ.It is seen that under extrusion wheel velocities of 6 and 8 RPM the grain structures are larger and inhomogeneous. Under the extrusion wheel velocity of 10 RPM, the structure containing fine and uniform grains are obtained. A further increase in wheel velocity to 18 RPM slightly increases the grain size. Figures of Microstructure of Copper samples at various wheel velocities and extrusion ratio are shown below.



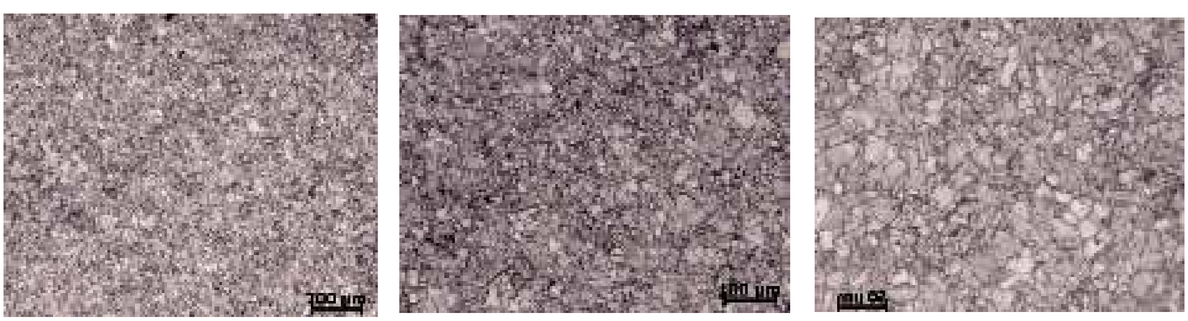
(a) **(b)** **(c)**

Figure 5.26: (a), (b), (c) shows the microstructures of Copper samples of 6mm size at 4 RPM at 50x, 100x and 200x respectively



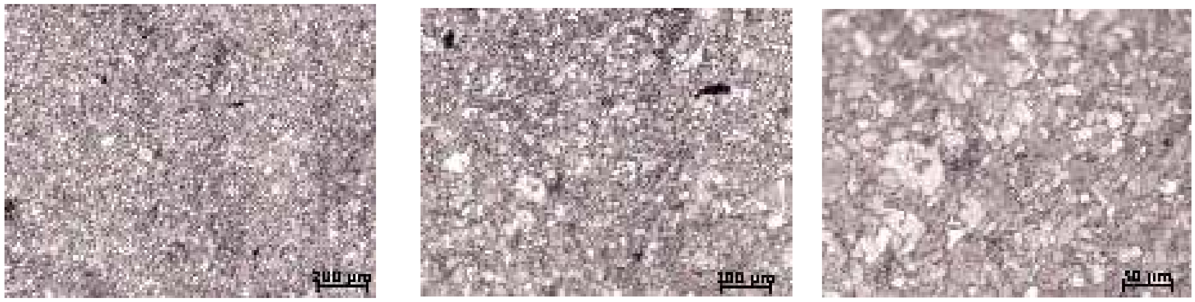
(a) **(b)** **(c)**

Figure 5.27: (a), (b), (c) shows the microstructures of Copper samples of 6mm size at 6 RPM at 50x, 100x and 200x respectively



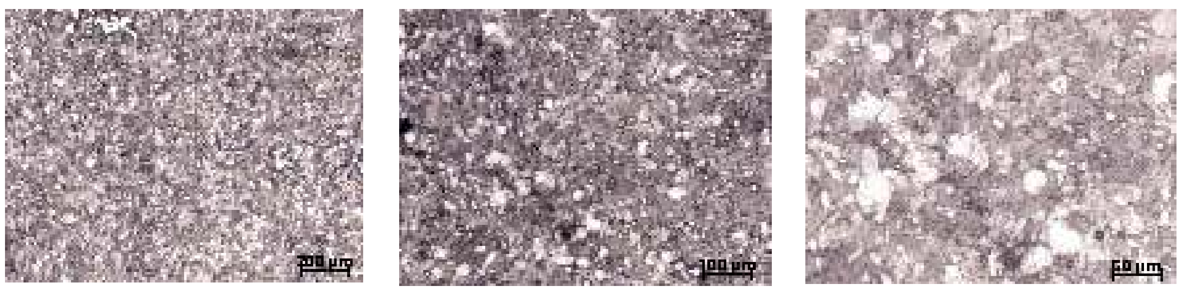
(a) **(b)** **(c)**

Figure 5.28 : (a), (b), (c) shows the microstructures of Copper samples of 6 mm size at 8 RPM at 50x, 100x and 200x respectively



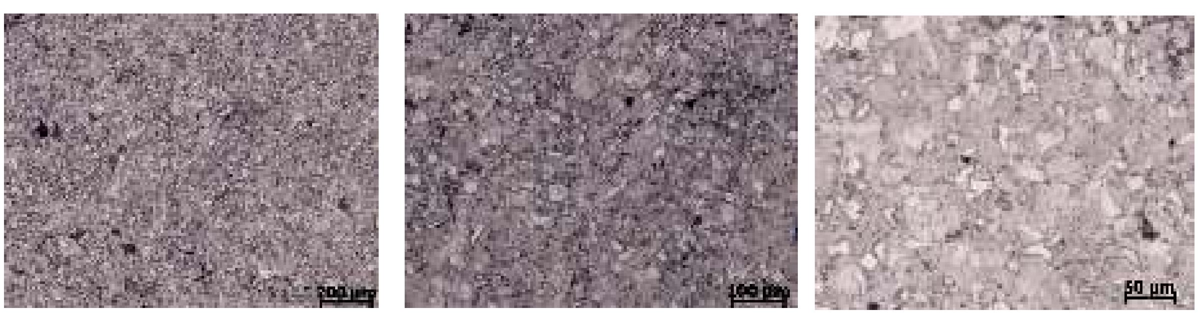
(a) **(b)** **(c)**

Figure 5.29: (a), (b), (c) shows the microstructures of Copper samples of 6 mm size at 10 RPM at 50x, 100x and 200x respectively



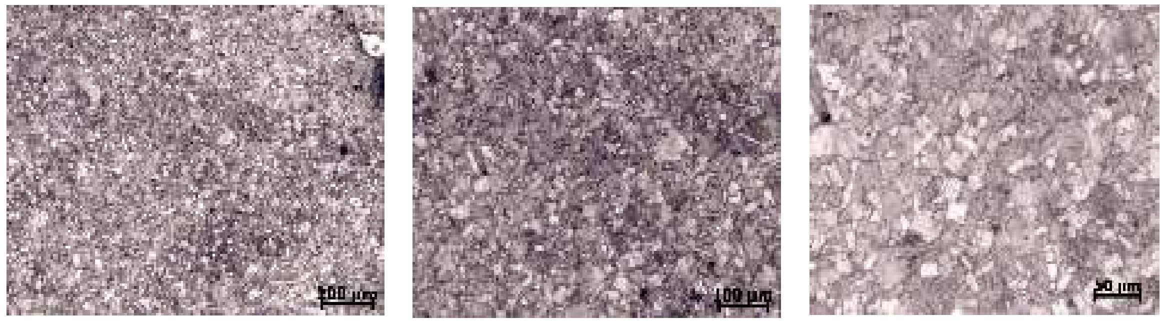
(a) **(b)** **(c)**

Figure 5.30: (a), (b), (c) shows the microstructures of Copper samples of 7 mm size at 4 RPM at 50x, 100x and 200x respectively



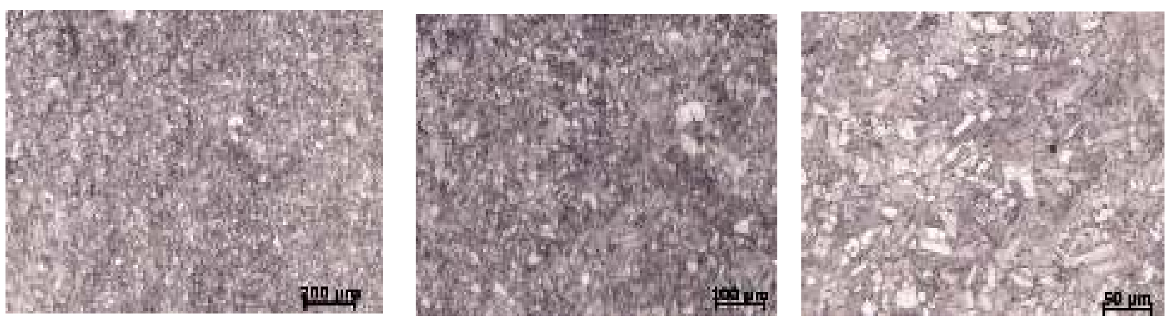
(a) **(b)** **(c)**

Figure 5.31: (a), (b), (c) shows the microstructures of Copper samples of 7mm size at 6 RPM at 50x, 100x and 200x respectively



(a) **(b)** **(c)**

Figure 5.32: (a), (b), (c) shows the microstructures of Copper samples of 7 mm size at 8 RPM at 50x, 100x and 200x respectively



(a) **(b)** **(c)**

Figure 5.33: (a),(b), (c) shows the microstructures of Copper samples of 7mm size at 10 RPM at 50x, 100x and 200x respectively

(a) **(b)** **(c)**

Figure 5.34: (a),(b), (c) shows the microstructures of Copper samples of raw feedstock of 12.5 mm size at 50x, 100x and 200x respectively

5.7 Tensile tests on Aluminum (Grade 1100)

Tensile test and Hardness test has been performed for finding the mechanical properties of the feedstock material used as well as of extruded product before and after deformation (extrusion) so as to compare the deformation characteristics under different extrusion wheel velocities and extrusion ratio. All the Aluminum feedstock has been extruded on the fabricated extrusion machine setup 2.

Tensile test for Aluminum

Tensile test samples for the raw feedstock material as well as of the extruded product under different wheel velocities and extrusion ratio have been prepared. Figures 5.35 and 5.36 below shows the tensile test specimens of 6 mm and 7 mm extruded Aluminum rod respectively.

Figure 5.35: Tensile sample for 6 mm Gauge Length = 15.6 mm, Gauge diameter =4.5 mm

Figure 5.36: Tensile sample for 7mm and 8mm extruded Aluminum rod

Gauge length=15.6 mm, Gauge diameter=4.5 mm

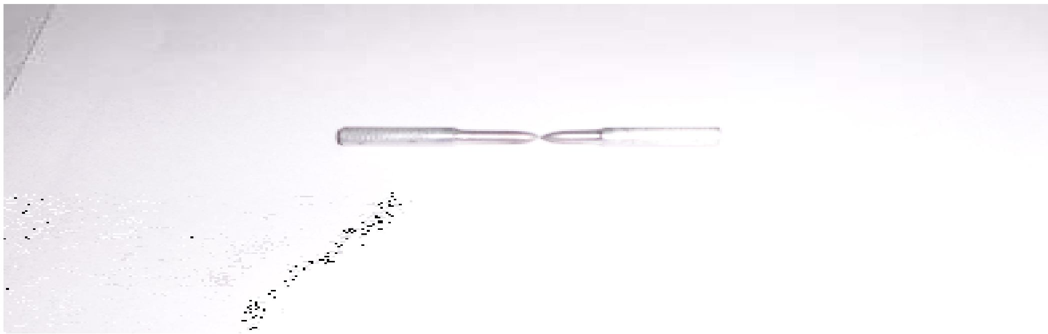


Figure 5.37: Fractured tensile test sample of extruded Aluminum alloy

Figure 5.37 above shows the fractured tensile test specimens of 6 mm and 7 mm extruded Aluminum rod.

Table 5.9: Tensile test result (Aluminum samples)

S. No.	Sample details	Max. Displace-ment (mm)	Max. Load (kN)	Max. Strength (MPa)	Breaking Displace-ment (mm)	Breaking Load (kN)	0.2% Yield Strength (MPa)	Energy Break (J)	% Elongation
1.	6 mm, 6 RPM	4.020	1.691	106.3	7.332	1.076	39.67	11.01	41.56
2.	6 mm, 8 RPM	3.228	1.651	103.8	6.067	1.052	64.99	9.195	37.23
3.	6 mm, 10 RPM	4.220	1.678	105.5	7.148	1.023	39.84	10.57	32.87
4.	7 mm,6 RPM	3.55	1.697	106.7	39.59	1.007	22.45	14.50	45
5.	7 mm,8 RPM	2.95	1.662	104.5	5.88	1.055	25.66	8.94	42.8
6.	7 mm,10 RPM	3.418	1.686	106.0	6.35	1.058	29.88	9.543	45
7.	8 mm,6 RPM	2.900	1.675	105.3	5.918	1.009	53.68	8.968	44
8.	8 mm,8 RPM	3.210	1.635	102.8	5.909	1.052	55.03	8.766	45
9.	8 mm, 10 RPM	3.280	1.643	104.2	6.292	1.012	42.75	9.322	46
10.	Raw material of diameter 9.5 mm	1.470	1.868	99.8	4.242	1.052	76.64	6.989	32

Table 5.9 above shows the tensile test result of Aluminum samples. Table 5.10 shows the chemical composition of pure copper feedstock material before and after extrusion.

Table 5.10: Chemical composition of Pure Copper feedstock before and after extrusion

Elements	Percentage (%)
Copper	99.99

Oxygen	0.01

Table 5.11: Tensile test result (Copper samples)

S. No.	Sample details	Max. Displace-ment (mm)	Max. Load (kN)	Max. Strength (MPa)	Breaking Displace-ment (mm)	Breaking Load (kN)	0.2% Yield Strength (MPa)	Energy Break (Joule)	% Elongation
1	6 mm, 4 RPM	10.18	4.011	252.2	13.29	1.460	87.27	44.44	55.14
2	6 mm, 6 RPM	8.89	4.008	252.0	11.24	2.628	90.81	38.86	53.03
3	6 mm, 8 RPM	8.08	4.024	253.0	10.92	1.930	86.76	37.16	51.45
4	6 mm, 10 RPM	6.30	4.083	256.7	9.01	2.623	118.70	32.79	44.57
5	7 mm, 4 RPM	6.820	3.944	250.2	9.930	2.242	95.1	32.70	54.87
6	7 mm, 6 RPM	6.730	3.957	248.8	9.828	1.401	102.3	32.05	59.85
7	7 mm, 8 RPM	6.400	3.952	248.5	9.540	1.627	86.9	31.59	59
8	7 mm, 10 RPM	6.300	3.941	250.0	9.168	1.793	55.2	30.23	52.46
9	Raw material of diameter 12.5mm	5.130	3.648	234	7.440	1.458	127.9	22.11	43

Table 5.11 above shows the tensile test result of copper samples. In table 5.11 we can see that as extrusion as product diameter decreases from 6 to 7 mm, the Yield strength value increases due to reduced extrusion ratio and hardening effect.

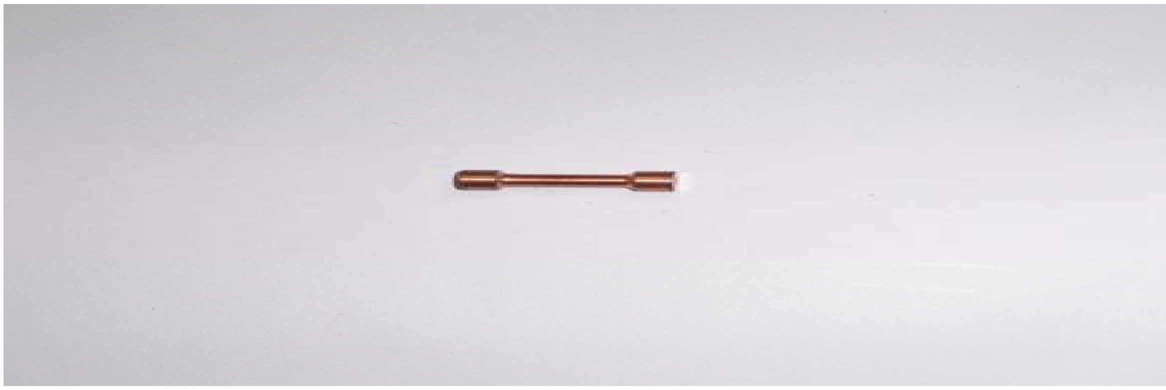


Figure 5.38: Tensile sample of extruded Copper rod (Gauge Length=15.6 mm, Gauge diameter = 4.5 mm)

Figure 5.39: Fractured tensile sample of extruded Copper rod

Figure 5.38 and 5.39 above shows the tensile test sample of extruded copper rod before and after fracture respectively.

5.8 Hardness Test for Aluminum Samples

The cut samples are rubbed on the emery paper of 1000 grade to finish the faces so that Hardness test can be performed on the samples for getting the exact value of Hardness. Hardness test has been performed for cut circular sample. All the hardness testing of the samples is performed on Vickers Hardness testing machine in which digital dial indicator is incorporated for reading the value of Vickers Hardness number. The load of 1 kg has been applied on the samples for making indentation on the prepared samples. For every test three readings has been taken and finally average Hardness value of the sample is determined. Figure 5.40 and 5.41 below shows the hardness test samples of Aluminum and copper feedstock materials before and after extrusion respectively.

Figure 5.40: Hardness test sample of Aluminum alloy before and after extrusion

Figure 5.41: Hardness test samples of Copper rod before and after extrusion

Table 5.12: Hardness test result of Aluminum alloy samples

S. No.	Sample detail	Average Hardness on Vickers Scale
1	6 mm,4 RPM	29.1
2	6 mm,6 RPM	33.2
3	6 mm,8 RPM	30.2
4	6 mm,10 RPM	29.4
5	7 mm,4 RPM	30.4
6	7 mm,6 RPM	34.8
7	7 mm, 8 RPM	32.1
8	7 mm,10 RPM	30.6
9	8 mm,4 RPM	31.2
10	8 mm,6 RPM	32.3
11	8 mm,8 RPM	32.5
12	8 mm.10 RPM	32.1
13	Raw material of diameter 9.5 mm	28.8

Table 5.12 above shows the hardness test result for Aluminum samples.

Table 5.13 below shows the hardness test result for copper samples.

Table 5.13: Hardness test result of Copper samples

S. No.	Sample detail	Average Hardness on Vickers Scale
1	6 mm,4 RPM	71.4
2	6 mm,6 RPM	72.2
3	6 mm,8 RPM	89.3
4	6 mm,10 RPM	74.5
5	7 mm,4 RPM	68.5
6	7 mm,6 RPM	66.6
7	7 mm,8 RPM	68.2
8	7 mm,10 RPM	89.1
9	Raw material of diameter 12.5mm	70.6

5.9 Graphical study of material properties of feedstock before and after extrusion for Aluminum and Copper alloy

In this section variation of material properties such as Hardness, Ultimate tensile strength, Yield strength etc of Aluminum and Copper alloy with extrusion wheel velocities and extrusion ratio has been cited and optimum parameter for enhancement of material properties after deformation (extrusion) has been visualized graphically.

Figure 5.42 shows the variation of Hardness with wheel velocity for Aluminum alloy. As the extrusion wheel velocity increases, the hardness of the extruded product increases initially, attains maximum value at certain wheel velocity and decreases thereafter as shown in Figure 5.42.

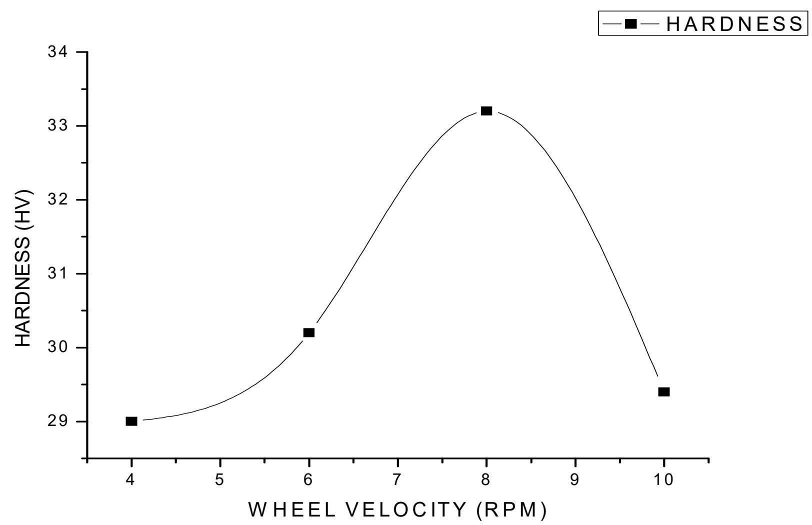


Figure 5.42: Variation of Hardness with wheel velocity (Aluminum alloy)

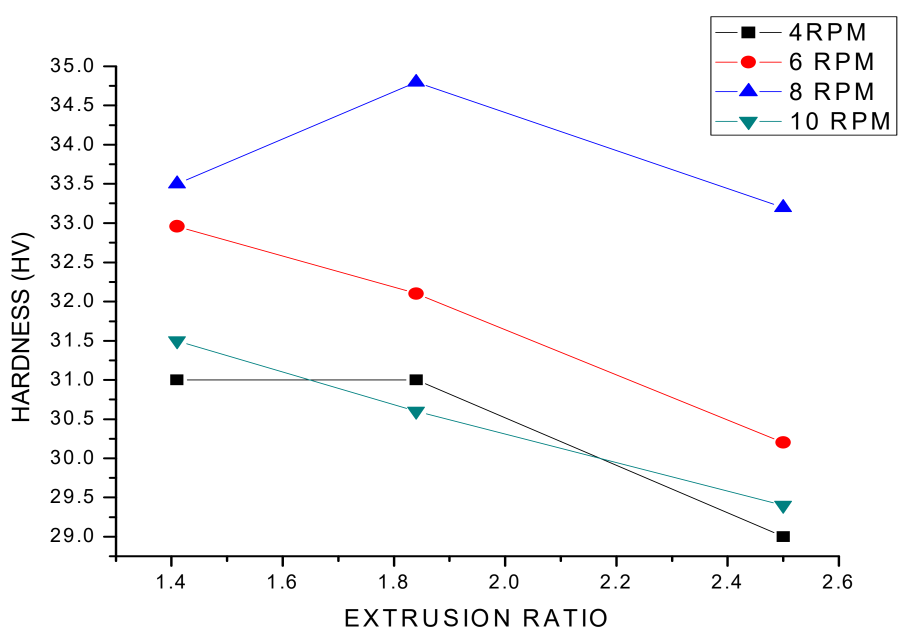


Figure 5.43: Variation of Hardness with extrusion ratio (Aluminum alloy)

Figure 5.43 shows the variation of Hardness with extrusion ratio for Aluminum alloy. In Figure 5.43 it can be observed that as the extrusion ratio increases the hardness of the extruded product decreases keeping wheel velocity as constant.

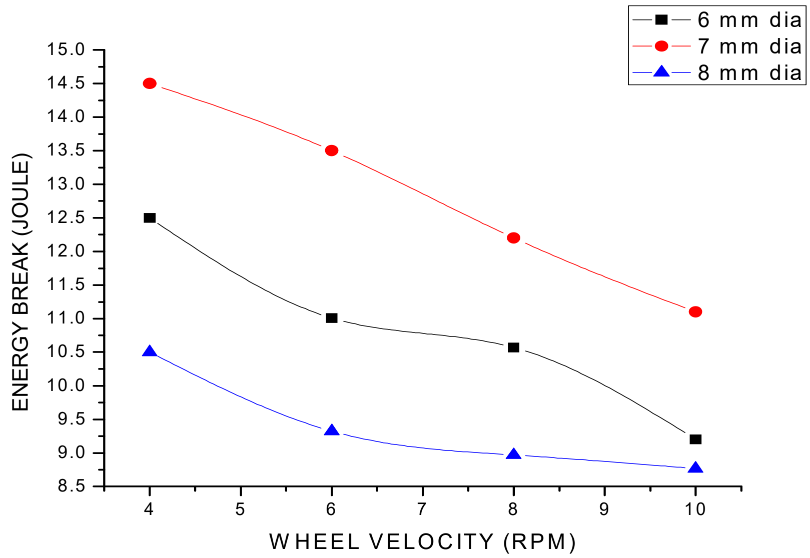


Figure 5.44: Variation of energy break with extrusion wheel velocity (Aluminum alloy)

Figure 5.44 shows the variation of energy break with extrusion wheel velocity for Aluminum alloy. As wheel velocity increases the energy required to break the product sample decreases keeping the extrusion ratio as constant as shown in Figure 5.44. In Figure 5.44, 6 mm, 7 mm and 8 mm diameter represents the extrusion ratio of 2.5, 1.84 and 1.41 respectively.

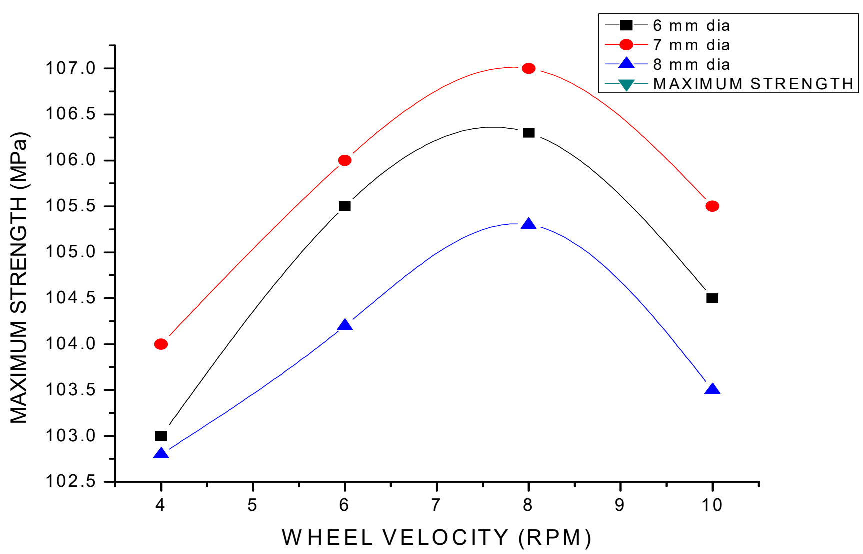


Figure 5.45: Variation of Maximum strength with extrusion wheel velocity (Aluminum alloy)

Figure 5.45 shows the variation of Maximum strength with extrusion wheel velocity for Aluminum alloy. As wheel velocity increases, the maximum strength value of extruded product sample increases initially and becomes maximum at a particular value of wheel velocity and then decreases thereafter keeping the extrusion ratio as constant as shown in Figure 5.45. In Figure 5.45 6 mm, 7 mm and 8 mm diameter represents the extrusion ratio of 2.5, 1.84 and 1.41 respectively.

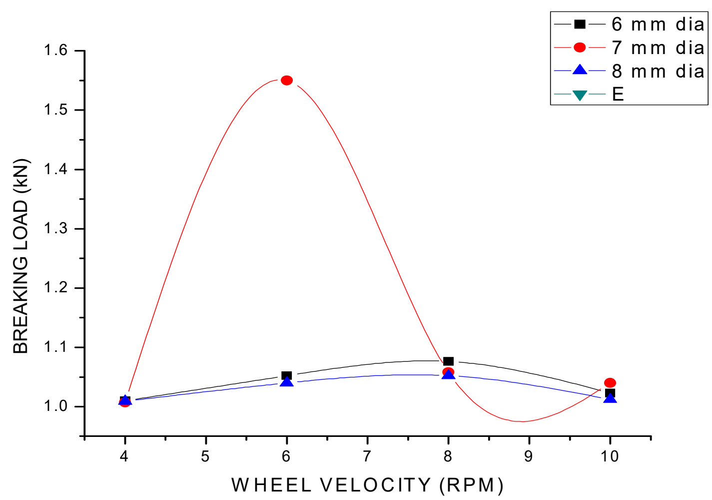


Figure 5.46: Variation of breaking load with extrusion wheel velocity (Aluminum alloy)

Figure 5.46 shows the variation of breaking load with extrusion wheel velocity for Aluminum alloy. As the wheel velocity increases the breaking load required for the extruded product sample initially increases, becomes maximum at a particular value of wheel velocity and then decreases thereafter as shown in Figure 5.46.

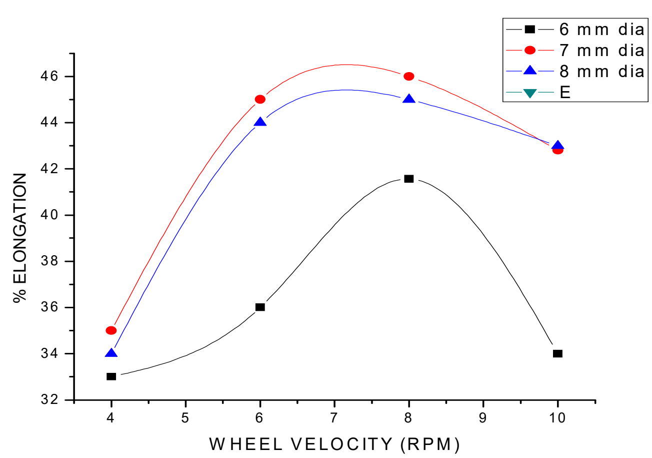


Figure 5.47: Variation of % Elongation with extrusion wheel velocity (Aluminum alloy)

Figure 5.47 shows the variation of % Elongation with extrusion wheel velocity for Aluminum alloy. As the extrusion wheel velocity increases, the % elongation of the extruded product samples increases initially, becomes maximum at a particular value of wheel velocity for a given value of extrusion ratio and decreases thereafter as shown in Figure 5.47. In Figure 5.47 6 mm, 7 mm and 8 mm diameter represents the extrusion ratio of 2.5, 1.84 and 1.41 respectively.

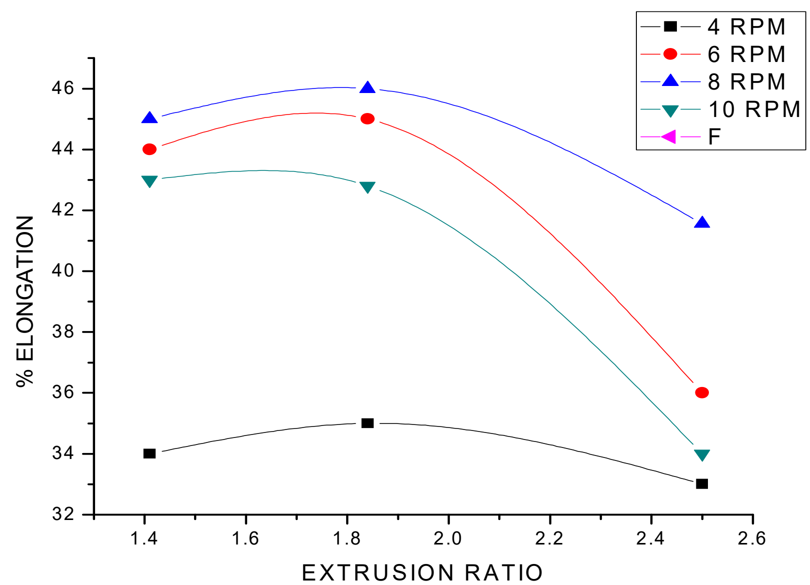


Figure 5.48: Variation of % Elongation with extrusion ratio (Aluminum alloy)

Figure 5.48 shows the variation of % Elongation with extrusion ratio for Aluminum alloy. As the extrusion ratio increases, the % elongation of the extruded product samples increases initially, becomes maximum at a particular value of extrusion ratio for a given value of extrusion wheel velocity and decreases thereafter as shown in Figure 5.48.

Figure 5.49 shows the variation of Energy break with extrusion ratio for Aluminum alloy. As the extrusion ratio increases, the energy break of the extruded product samples increases initially, becomes maximum at a particular value of extrusion ratio for a given value of extrusion wheel velocity and decreases thereafter as shown in Figure 5.49.

Figure 5.50 shows the variation of 0.2% Yield strength with extrusion ratio for Aluminum alloy. As the extrusion ratio increases, the Yield strength value of the extruded product samples decreases initially, becomes minimum at a particular value of extrusion ratio for a given value of extrusion wheel velocity and increases thereafter as shown in Figure 5.50.

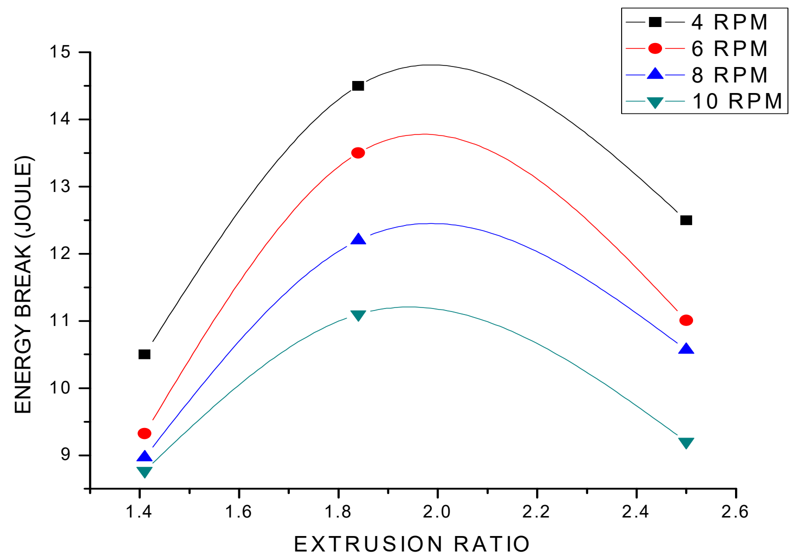


Figure 5.49: Variation of Energy break with extrusion ratio (Aluminum alloy)

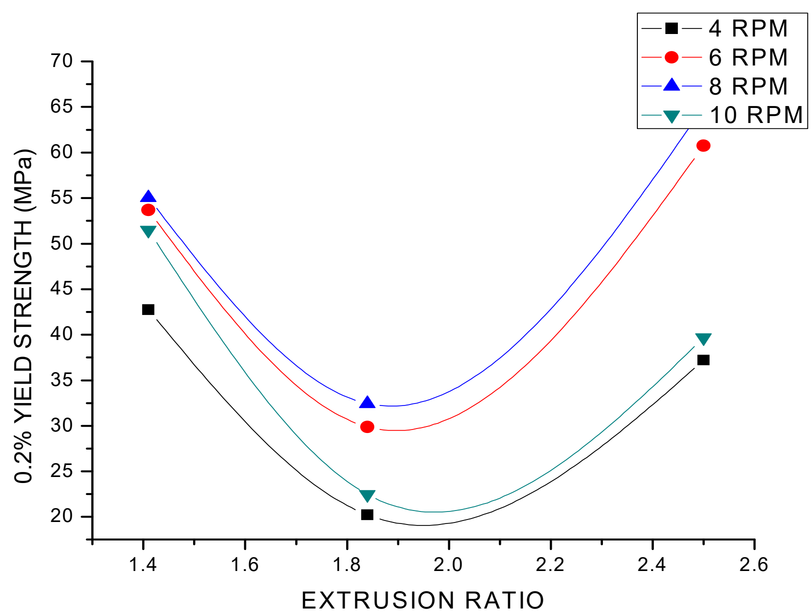


Figure 5.50: Variation of 0.2% Yield strength with extrusion ratio (Aluminum alloy)

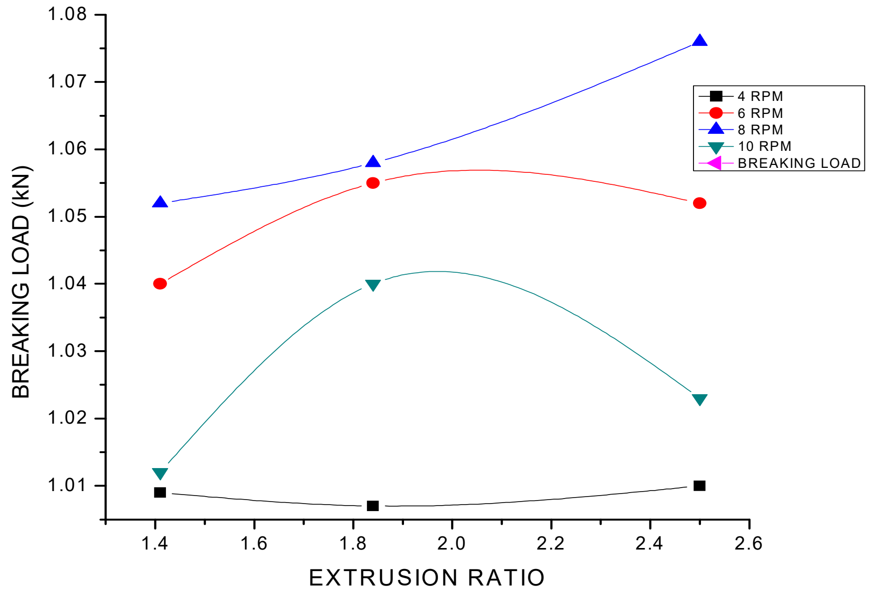


Figure 5.51: Variation of energy break with extrusion ratio (Aluminum alloy)

Figure 5.51 shows the variation of energy break with extrusion ratio Aluminum alloy. It can be observed that as the extrusion ratio increases, the breaking load increases initially and then becomes maximum at a particular value of extrusion ratio and then decreases with further increase in the value of extrusion ratio for a given value of extrusion wheel velocity as shown in Figure 5.51.

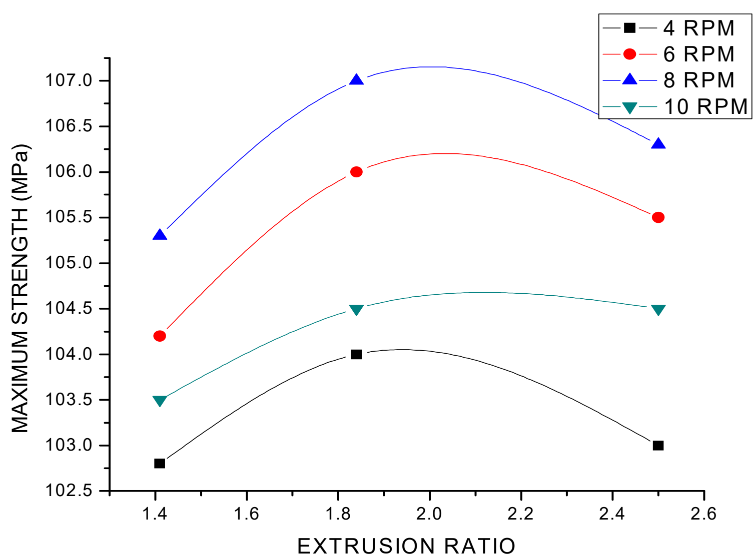


Figure 5.52: Variation of Maximum strength with extrusion ratio (Aluminum alloy)

Figure 5.52 shows the variation of Maximum strength with extrusion ratio for Aluminum alloy. As the extrusion ratio increases, the maximum strength of the extruded product samples increases initially and becomes maximum at a particular value of extrusion ratio and then decreases with further increase in the value of extrusion ratio for a given value of extrusion wheel velocity as shown in Figure 5.52.

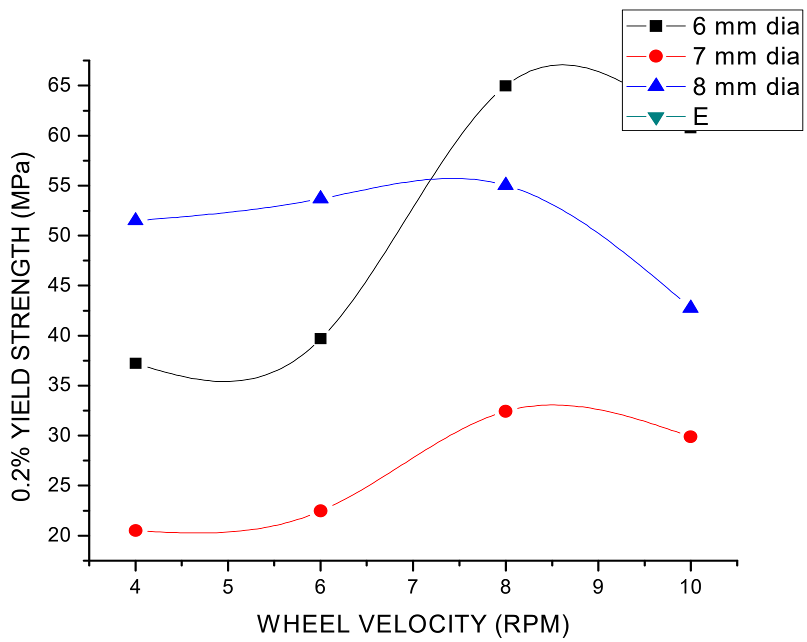


Figure 5.53: Variation of 0.2% Yield strength with extrusion wheel velocity (Aluminum alloy)

Figure 5.53 shows the variation of 0.2% Yield strength with extrusion wheel velocity for Aluminum alloy. As the extrusion wheel velocity increases, the yield strength value of the extruded product samples increases initially and becomes maximum at a particular value of extrusion wheel velocity and decreases further with increase in the value of wheel velocity for a given value of extrusion ratio as shown in Figure 5.53.

Figure 5.54 shows the variation of Hardness with extrusion wheel velocity for Copper alloy. It can be observed that the hardness value of the extruded product samples of copper alloy increases with increase in the value of extrusion wheel velocity and the attains a common maximum value at a particular value of extrusion wheel velocity and decreases thereafter with further increase in the value of wheel velocity for a given value of extrusion ration as shown in Figure 5.54.

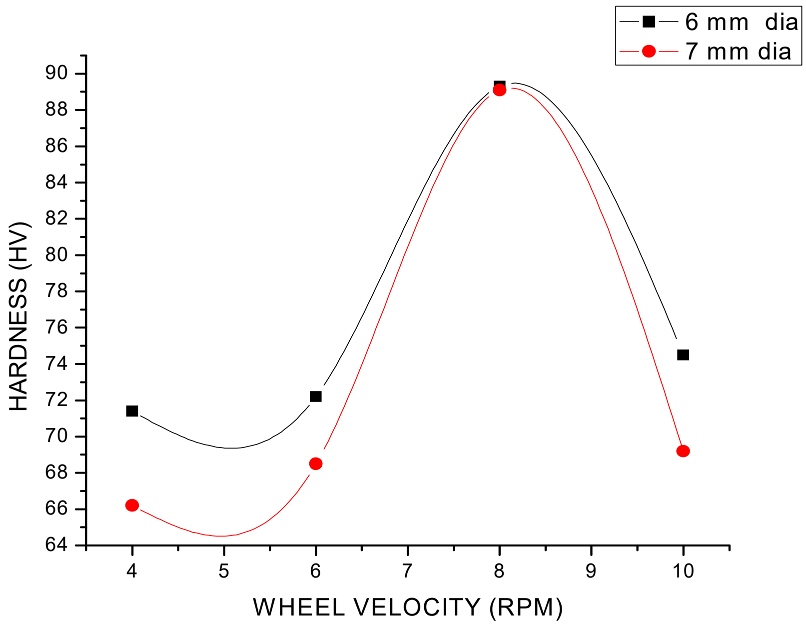


Figure 5.54: Variation of Hardness with extrusion wheel velocity (Copper alloy)

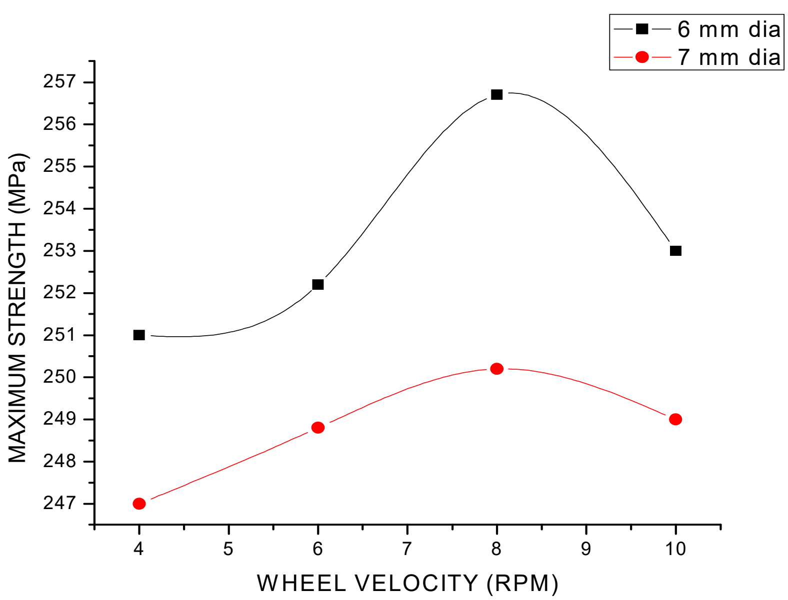


Figure 5.55: Variation of Maximum strength with extrusion wheel velocity (Copper Alloy)

Figure 5.55 shows the variation of Maximum strength with extrusion wheel velocity for Copper Alloy. As the extrusion wheel velocity increases, the maximum strength of the extruded copper product samples increases initially and attains a maximum value at a particular wheel velocity and decreases with further increase in the value of wheel velocity for a given value of extrusion ratio as shown in Figure 5.55.

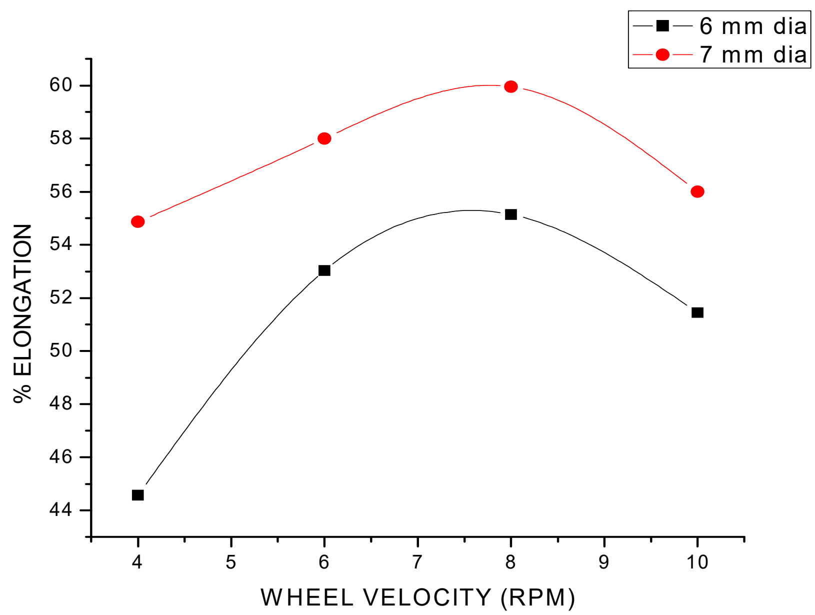


Figure 5.56: Variation of % Elongation with extrusion wheel velocity (Copper alloy)

Figure 5.56 shows the variation of % Elongation with extrusion wheel velocity for Copper alloy. It can be observed that as the extrusion wheel velocity increases, % Elongation of the extruded copper product samples increases and assumes a maximum value at a particular value of wheel velocity and then decreases to a certain value with further increase in the value of wheel velocity for a given value of extrusion ratio as shown in Figure 5.56.

Figure 5.57 shows the variation of 0.2% Yield strength with extrusion wheel velocity for Copper alloy. As the extrusion wheel velocity increases, the Yield strength of the extruded copper product samples increases initially and attains a maximum value at a particular value of extrusion wheel velocity and decreases with further increase in the value of wheel velocity at a given value of extrusion ratio as shown in Figure 5.57.

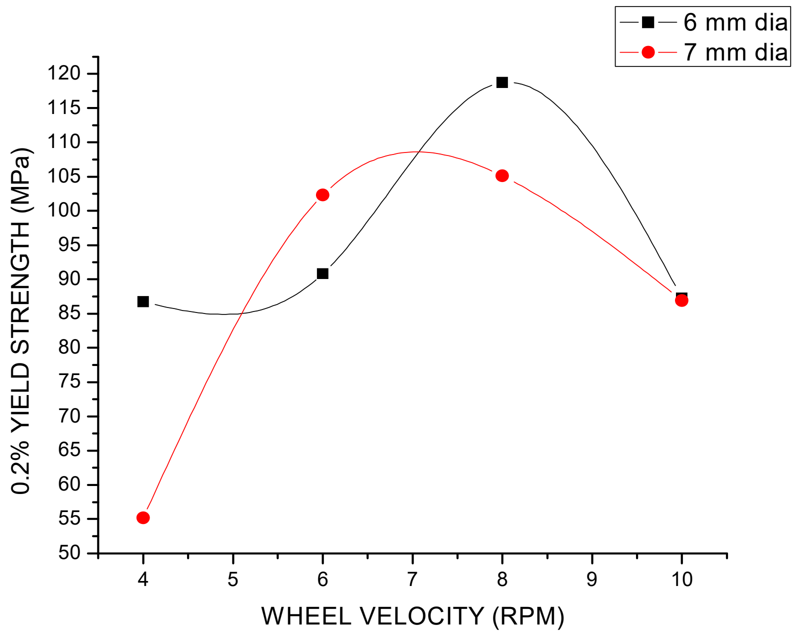


Figure 5.57: Variation of 0.2% Yield strength with extrusion wheel velocity (Copper alloy)

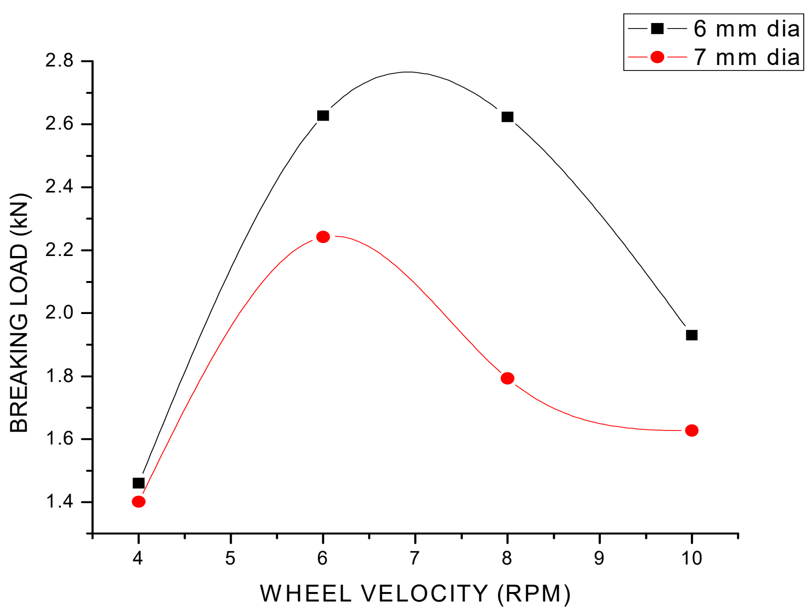


Figure 5.58: Variation of breaking load with extrusion wheel velocity (Copper alloy)

Figure 5.58 shows the variation of breaking load with extrusion wheel velocity for Copper alloy. As the extrusion wheel velocity increases, the breaking load required by the extruded product samples of copper alloy increases initially and becomes maximum at a particular value of wheel velocity and decreases thereafter for a given value of extrusion ratio as shown in Figure 5.58.

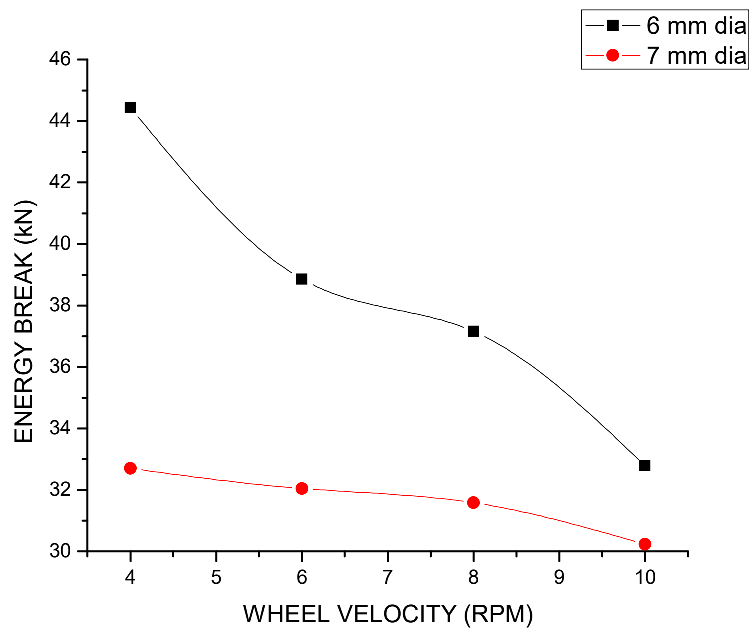


Figure 5.59: Variation of Energy break with extrusion wheel velocity (Copper alloy)

Figure 5.59 shows the variation of Energy break with extrusion wheel velocity for Copper alloy. As the extrusion wheel velocity increases, the energy break required decrease continuously for a given value of extrusion ratio for the extruded product samples as shown in Figure 5.59. In Figures 5.54 - 5.69, curves has been plotted for a given value of extrusion ratio 4.34 and 3.18 which corresponds to 6 mm diameter and 7mm diameter of extruded product of copper alloy respectively.

In this chapter experimental studies have been performed on different metals and alloys like Aluminum and Copper. The fabricated and commercial Continuous Extrusion machine setup has been used for the extrusion of circular rod of diameters 9.5 and 12.5 mm and results (products) has been found satisfactory. A validation has been performed for Aluminum (Al 1100) and Copper (C 101) and results have been compared with simulation. Therefore, the good agreement has been achieved between simulation and experimental study and prediction process is possible. The effect of different parameters on total extrusion power has been presented.

For extrusion of 9.5 mm Aluminum feedstock material, the total power required for extrusion have been observed as 18.92 kW, 18.48 kW, 17.6 kW and 16.94 kW for extrusion ratio of 2.5 at wheel velocities of 4 RPM, 6 RPM, 8 RPM and 10 RPM respectively.

For extrusion of 9.5 mm Aluminum feedstock material, the total power required for extrusion have been observed as 18.26 kW, 17.38 kW, 16.72 kW and 16.41 kW for extrusion ratio of 1.84 at wheel velocities of 4 RPM, 6 RPM, 8 RPM and 10 RPM respectively.

For extrusion of 9.5 mm Aluminum feedstock material, the total power required for extrusion have been observed as 17.6 kW, 17.16 kW, 16.28 kW and 16.06 kW for extrusion ratio of 2.5 at wheel velocities of 4 RPM, 6 RPM, 8 RPM and 10 RPM respectively.

Characterization of Continuous Extrusion process like microstructure analysis and parametric study including comparison between simulation and experimental results are also performed in this chapter. Microstructure analysis of the extruded products of Aluminum and Copper before and after deformation (extrusion) has been carried out. Material properties of Aluminum and Copper have been found using tensile and hardness test. Finally, a brief parametric study of Continuous Extrusion process by comparing simulation and experimental results has been carried out.

The microstructure images of all the samples show no considerable changes of grain size during before deformation (extrusion) but the shape of grains is changed as they are elongated after deformation (extrusion). The feedstock before continuous extrusion has uniform grains. The average size of the extruded alloy under extrusion wheel velocity ranging from 6 to 8 RPM ranges from 80μ to 200 μ.It is seen that under extrusion wheel velocities of 6 and 8 RPM the grain structures are larger and inhomogeneous. Under the extrusion wheel velocity of 10 RPM, the structure containing fine and uniform grains are obtained. A further increase in wheel velocity to 18 RPM slightly increases the grain size.