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Cold Extrusion of Carbon Electrodes Using Dies of CRHS

Concept and Performance Analysis

Sami Abulnoun Ajeel

University of Technology, Bagdad, Iraq

E-mail: sami-tech@yahoo.com

Ahmed M. Saleem

Technical College, Mosul, Iraq

E-mail: ah_ms1971@yahoo.com

Farhad B. Bahaideen

School of Mechanical Engineering

Universiti Sains Malaysia

14300 Nibong Tebal, Penang, Malaysia

E-mail: farhadbilal62@yahoo.com

M. Abdul Mujeebu (Corresponding author)

School of Mechanical Engineering

Universiti Sains Malaysia

14300 Nibong Tebal, Penang, Malaysia

Tel: 60-1-4305-1476 E-mail: mamujeeb5@yahoo.com

Hussain J. Mhamed Alalkawi

University of Technology, Bagdad, Iraq

E-mail: alalkawi2007@yahoo.com

Abstract

In this article cold extrusion of carbon electrodes using the direct extrusion die that is designed using one of the theoretical concepts, Constancy of the Ratio of the Successive Generalized Homogeneous Strain-increment (CRHS), is presented. On the basis of the above concept we used three types of dies that are categorized as uniform (UCRHS), accelerated (ACRHS), and decelerated (DCRH) according to the deformation rates. All dies were with fixed reduction area of 50%. The mixture used (filler with binder) was extruded in round section carbon electrodes carried out at 60^{o}C to 80^{o}C. Ten samples are produced and tested for properties such as electrical resistivity, hardness, density and porosity. The results show that the extrusion die UCRHS is the more efficient die design for the production of carbon electrodes.

Keywords: Extrusion die, Carbon electrodes, CRHS, Binder ratio, Porosity

1. Introduction

Extrusion is used to produce the large electrodes for electric furnaces, small rods for dry cell batteries, finer grained graphite for molds used by the metallurgical industry, electrolytic anodes, and the bulk material from which certain motor and generator brushes are made. Traditionally, the extrusion processes can be divided into three types: forward extrusion, backward extrusion, and combined forward/backward extrusion. The extrusion processes can also be categorized by the operation temperature into hot, warm, and cold extrusion. Metal extrusion is a near-net-shape manufacturing process that can reduce the machining tasks. This process can be used to produce long and straight extrusion product such as gear spline, bar, wire, and seamless pipe. The die electrode is used to produce the extrusion die cavity [(Kao (2000)].

Regarding the axisymmetric extrusion, the Constancy of the Ratio of the Successive Generalized Homogeneous Strain-increment (CRHS) and the constancy of the Mean Strain Rate (CMSR) had been proposed and used by Vaidyanathan and Blazynski (1973) and Blazynski and Lee (1984) in obtaining the extrusion die profile. Some other

generalised die profiles, such as conic functions by Chen and Ling (1968) and streamline by Yang et al. (1986) were also used in creating uniform extrusion flow and obtaining smaller extrusion load.

As far as the authors are aware, use of CRHS dies for extrusion of carbon electrodes has not been published so far. Against this background, the current study focused on the application of CRHS dies for the cold extrusion of carbon electrodes. Three typical designs namely, 1) Decelerated Constancy of the Ratio of the successive generalized Homogeneous Strain-increment (DCRHS), 2) Accelerated Constancy of the Ratio of the successive generalized Homogeneous Strain-increment (ACRHS) and 3)Uniform Constancy of the Ratio of the successive generalized Homogeneous Strain-increment(UCRHS) have been used and tested for their efficiency. It has been found that UCRHS die design is the best for the application.

2. The CRHS Concept

CRHS is the abbreviation of 'Constancy of the Ratio of the Successive Generalized Homogeneous Strain-increment'. This concept of tool design is based upon the basis of homogeneous strain for the metal forming operation, which represents a function of the physical dimensions of the engineering material to be formed. The die surface profile or tool profile can be produced by using this concept, because the forming pass is divided into, number of sections (n) depending on the expression of CRHS through these sections as follows

$$\frac{\varepsilon_{H_2}-\varepsilon_{H_1}}{\varepsilon_{H_1}-\varepsilon_{H_0}} = \frac{\varepsilon_{H_3}-\varepsilon_{H_2}}{\varepsilon_{H_2}-\varepsilon_{H_1}} = \cdots\cdots\cdots = \frac{\varepsilon_{H_n}-\varepsilon_{H_{n-1}}}{\varepsilon_{H_{n-1}}-\varepsilon_{H_{n-2}}} = Constant = S \qquad (1)$$

Where ε_{Hn} is the value of homogeneous strain at the section 'n' through the forming pass. But S is a constant called 'Rate of Deformation', it does not depend on the time because it is related to the deformation rate and has no relation to the strain rate. The value of S can be taken randomly, if it has a value S<1, it means that the rate of deformation is 'Decelerated', and it has a sign of DCRHS. S=1, the rate of deformation is 'Uniform', and it has a sign of UCRHS. S>1, the rate of deformation is 'Accelerated', and it has a sign of ACRHS, as shown in Figure 1.

The constant S may take different values, but the experience in the metal forming tool design indicates that the range in between (0.8 –1.2) is sufficient for most applications. In this study, the value S = 0.9 is considered as a decelerated rate of deformation, and the value S = 1.2 for the accelerated rate [Kena (2007)].

3. The Extrusion Machine

Extrusion press illustrated in figure 2 consists of a jacketed cylindrical chamber known as the mud chamber which is filled with the mix. A separate molding operation known as preslugging is done by means of the vertical ram (Tamping ram) and the horizontal one known as extrusion ram forces the warm mix from the mud chamber through a reducer into a die of the desired shape. Another design of extrusion machine is the tilting type in which the mud chamber may be raised to vertical position to facilitate loading, and then lowered to a horizontal position in extrusion. Chamber adapter and dies are jacketed and are generally heated with steam or hot oil, or electricity.

A typical extrusion temperature for large electrodes is about 100 ^{o}C and extrusion pressure may range from 2.6 – 55 MPa. (400 – 8000 Psi), depending on the ratio of die area to mud chamber area, temperature and type of mix. Extrusion rate may be about 10 mm/s (24 in/min) at 16.8 MPa (2500 Psi) [Kirk and Othemer (1964&1978), Hibbler (1997)].

4. Extrusion Die

Figure 3 shows the extrusion die designed according to German specification (DIN). The basic parts of the die are as follows:

4.1 Container

It is a cylinder machined in the turning machine from steel (34 CrNiMo6) with inside diameter, 100 mm.

4.2 The Punch

The punch is machined from steel (X210Cr12/6) to have a good toughness against the force applied. It is turned and heated treated to 40 HRC and surface ground to ensure alignment with the container.

4.3 The base

The base of the press has a hole in the middle of it to have a good fitting between the die and the base.

4.4 Dies

1) Accelerated Constancy of the Ratio of the successive generalized Homogeneous Strain-increment (ACRHS), S= 1.2

2) Uniform Constancy of the Ratio of the successive generalized Homogeneous Strain-increment (UCRHS), S = 1 and

3) Decelerated Constancy of the Ratio of the successive generalized Homogeneous Strain-increment (DCRHS), S= 0.9

The material that was used in making the dies is X 155Cr V Mo 12 1/G which has a good hardness besides its ability to be heat treated up to 42 HRC. The reduction in all dies was 75%. Figure 4 shows a photograph of the dies, the container and the punch.

5. Extrusion Process

Extrusion process was done on die by using hydraulic press, type IVA LOLA RIBER with capacity of 40 tons at the University of Technology, Bagdad, Iraq. The die was kept at the base of the press in such a way that the outer surface of the die outlet fit into the inner side of base hole of the press. A light oil lubricant was used to lubricate the inside wall of the die and the container. Cold extrusion process was done at 80^0C by putting a heating element around the die. The slugging force was 2 MPa and the extrusion force was 3 MPa. Extrusion samples of 50 mm diameter and 150 mm long have been produced whose details are given in table 1. A hollow cylinder was putted under the base of the press to let the samples flow outside. Turning was done for some samples for using them in the tests, the forces used were the highest, and sufficient forces for the dies that were used in extrusion process, except the die (DCRHS) with deformation ratio of (S = 0.9) which needed high force (more than 7 MPa). This force indicates that the die was less efficient than the other dies. The products made by dies of type ACRHS and DCRHS show outside cracks and poor service finish, hence the electrodes made by them were rejected. Many experiments have been done by using the die UCRHS with the same filler mixture for different binder ratios (27%, 29%, 31%, 32%, 33%, and 34%) and for different binder temperatures (60^0C, 70^0C, 80^0C, 90^0C, 100^0C, and 120^0C) . Also, experiment was done to measure the time and velocity for electrode extrusion of 150 mm with different binder ratios.

6. Testing of Carbon Electrode Samples

Carbon electrodes tests include the following:

6.1 Electrical Resistively Test

The Electrical resistively of the samples were measured by using high sensitivity digital Avo meter. The temperature coefficient of resistance was calculated by taking measurements under different temperatures using a furnace (type HP) with a maximum temperature 500 ^{o}C. The temperatures were measured using thermo couples (type K) attached to the sample. A graph between current and voltage was plotted, and specific sensitivity Pc and the electric resistance R were calculated as follows,

$$P_c = R\frac{A}{L} \tag{1}$$

where,

L is the length of the samples, A, cross section area of the contact

Temperature coefficient of resistance can be calculated as:

$$R_T = \frac{R_t}{1+\alpha_T(t-T)} \tag{2}$$

where,

R_T, electric resistance at room temperature, R_t, electric resistance at the known temperature,

and α_T, temperature coefficient of resistance which is obtained from,

$$\alpha_T = \frac{R_t - R_T}{R_T(t-T)} \tag{3}$$

6.2 Hardness test

In this test Brenell hardness tester model (Wilson B554T) was used. The applied load was 0.6 kg and the diameter of the ball indenter was 2.5 mm. Then, the LIETZ optical microscope was used to measure the diameter of the indent. The H.B. was calculated using equation [Mohamed Ali (2002)],

$$BHN = \frac{2P}{\pi D^2(1-\sqrt{(1-d^2/D^2)})} \tag{4}$$

where:

P, load in kg, D, diameter of the ball in mm, and d, diameter of the impression in mm.

6.3 Density and Porosity Measurements

In this measurement the typical way (20 – 83) ASTM was used. The upper and the lower surfaces were ground by a samfering paper. First the dry sample is weighed in air then dropped in boiled water, and kept at the same temperature for six hours then the sample and the water are left to cool. The sample is then weighed in water and out of water after the two surfaces are slightly cleaned with a piece of cotton. Then it is baked for twelve hours in a furnace, and is weighted again after baking.

The density of the sample can be calculated by

$$\rho = \frac{D}{V} \tag{5}$$

Where,

D, the weight after backing, V , volume of sample obtained from,

$$V = (W - S)\rho' \tag{6}$$

where, W, weight out of water after cleaning, S, weight in water and ρ' density of water equal to 1 g/cm^3.

The volume of open pores V^I and the volume of prevision portions V^{II} in cm^3 can be calculated as follows

$$V' = (W - D)\rho' \tag{7}$$

$$V'' = (D - S)\rho' \tag{8}$$

Apparent porosity P is calculated from,

$$P = \frac{(W - D)}{V}\rho' * 100\% \tag{9}$$

Water absorption A is obtained from the equation,

$$A = \frac{(W - D)}{D} * 100\% \tag{10}$$

And apparent specific gravity T can be calculated from equation,

$$T = \frac{D}{D - S} \tag{11}$$

7. Results and Discussion

Carbon electrode extrusion is one of forming operations which occurs at a degree less than recrystallization temperature and leads to have strain hardening in the material. Its degree depends on the value of strain which depends on the redundant ratio and causes to improve the mechanical properties. This result is well-suited with that of previous work (Mohamed Ali S., 2002). The dies with UCRHS have a less strain redundancy factor among all the dies and have the shortest length for different extrusion temperatures.

7.1 Density, porosity, and water absorption

The results of density, porosity, and water absorption test are shown in table 2. A comparison with the product of S.G.L. Group Company is shown in figure 5 .The curve shows the result of this research which is compatible with the result of the company.

7.2 Hardness

The result of hardness test is shown in table 3. This result is compatible with that of published work [Farook (1999)]. Figure 6 shows the relationship between the density and the hardness of the samples.

7.3 Effect of Extrusion on Hardness

The sample showed high compression stress as the porosity already present in the material has been minimized by compressing the material before extrusion, which leads to increase in hardness and tensile resistance. This result is well-matched with that of published work [Salam (1996)].

7.4 Electrical Resistivity

The electrical resistively is shown in table 4. The results are is good agreement with other workers [Kirk and Othemer (1964&1978)]. Figure 7 shows the relationship between the density and the resistivity of the samples.

7.5 Effect of Binder Temperature on Extrusion Process

There is a limit for binder temperature through which extrusion process can be done. This limit is found to be 60 ^{o}C to 80^{o}C for the surface of the mixture near the internal surface of the container and the die, and 90 ^{o}C to100^{o}C for the outer surface of the container and the die. It has been experienced that the temperature of the mixture near the container surface should be more than that of the remaining part of the mixture by 20^{o}C to simplify the forming process, and get a good fluidity of the mixture in and out the die.

7.6 Effect of Binder Ratio on Extrusion Process

The extrusion velocity increases by increase of binder ratio by non linear relationship which can be expressed by the function $T = AB^{-\alpha}$. For the coke and binder used, the minimum binder ratio is found to be 31% for extrusion process. For a ratio 27% – 30%, the extrusion process is too hard and the miture has no plasticity to form carbon electrode. Fig. 8 shows the variation of time versis binder ratio. It is clear that the binder ratio decrease with increase the time and sharply variation at the time (145 - 10) sec.

7.7 Effect of Friction on Extrusion Process

The extrusion product at the first time had a crack at the surface because of the surface resistance of the die and the container. This problem was solved by the following actions

1) The surface grinding of both die and container.

2) The careful use of lubricant.

3) Increase in extrusion force.

Surface grinding for both small scale die and container is very important because of high friction. The use of lubricant for 2 cm^3/kg of the mixture was very necessary.

8. Conclusion

The cold extrusion process of carbon electrode forming by using CRHS die designing concept is being presented. Three typical die designs such as accelerated (ACRHS), uniform (UCRHS) and decelerated (DCRHS) were used for the process and the samples in each case were tested for their quality. From the result analysis, the following conclusions are drawn

1) The best temperature of the mixing (the filler and the binder) is 100 ^{o}C – 120^{o}C.

2) The best temperature of the extrusion is 100 ^{o}C for outside wall of the container and 80 ^{o}C – 90^{o}C for inside wall of the container.

3) The best die is UCRHS.

4) The force needed for preslugging the mixture is 2 MPa.

5) The force needed for extruding the electrode is 3 MPa.

6) The electrode can be produced successfully by direct cold extrusion.

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Table 1. Samples taken for electrodes

Symbol	Filler Type	Binder Ratio%	Type of Die
E1	Needle	31	UCRHS
E2	Needle	31	UCRHS
E3	Needle	31	UCRHS
E4	Needle	31	UCRHS
E5	Needle	31	UCRHS
E6	Needle	31	UCRHS
E7	Needle	31	UCRHS
E8	Needle	31	UCRHS
E9	Needle	31	UCRHS
E10	Needle	31	UCRHS

Table 2. Density, porosity, and water absorption for needle petroleum coke and binder samples

Sample no.	Density g/cm^3	Water absorption%	Porosity %
E1	1.63	11.52	25.38
E2	1.65	11.5	24.5
E3	1.69	10.8	22
E4	1.71	10.2	21.8
E5	1.70	10.3	21.9

Table 3. Hardness and density for needle petroleum coke and binder samples

Sample no.	Hardness	Density
E6	318	1.62
E7	319	1.66
E8	320	1.69
E9	322	1.70
E10	325	1.72

Table 4. Electrical resistively for needle petroleum coke and binder samples

Sample no.	Resistively Ohm - cm	Density g/cm^3
E6	0.291	1.62
E7	0.290	1.66
E8	0.275	1.69
E9	0.285	1.7
E10	0.270	1.72

Figure Legends

1. Figure 1. The compounds die (CRHS) surface profile along the die inlet-exit.
2. Figure 2. Extrusion machine for carbon electrode manufacture.
3. Figure 3. Schematic assembly drawing for extrusion die.
4. Figure 4. The dies, the container and the punch.
5. Figure 5. A comparison between the research result and SGL group company product.
6. Figure 6. Relationship between the density and hardness.
7. Figure 7. Relationship between density and the resistively
8. Figure 8. Variation of binder ratio with extrusion time for electrodes 50 mm diameter at constant pressure and temperature.

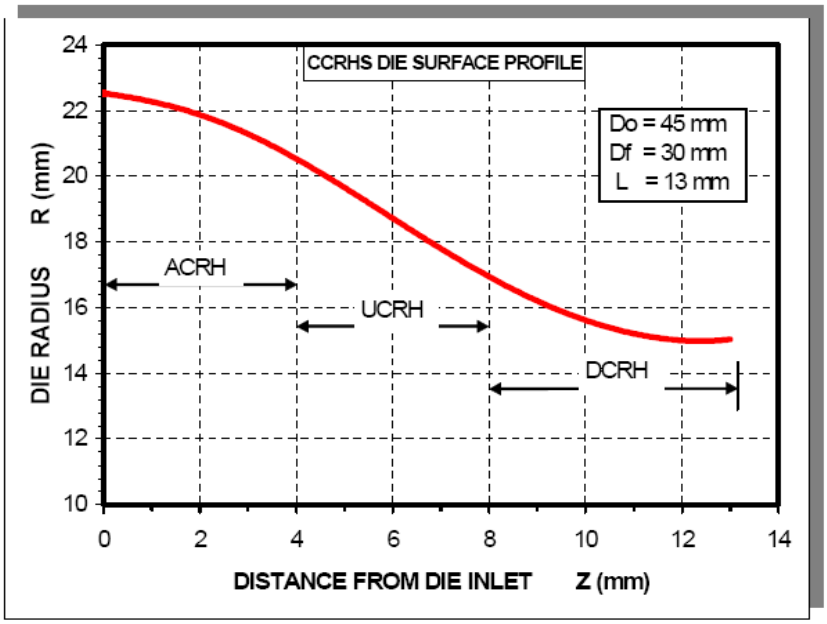


Figure 1.

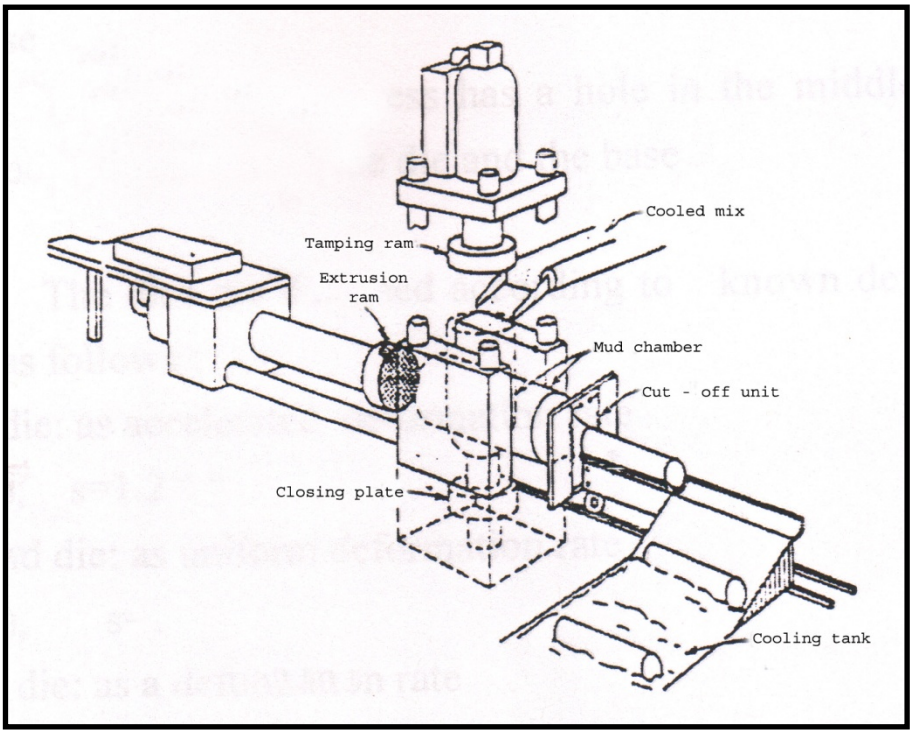
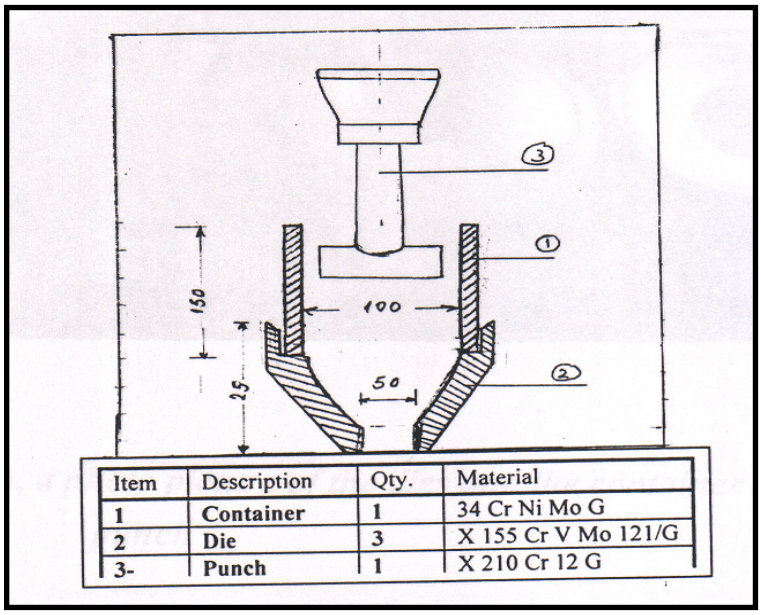


Figure 2.



Item	Description	Qty.	Material
1	Container	1	34 Cr Ni Mo G
2	Die	3	X 155 Cr V Mo 121/G
3-	Punch	1	X 210 Cr 12 G

Figure 3.

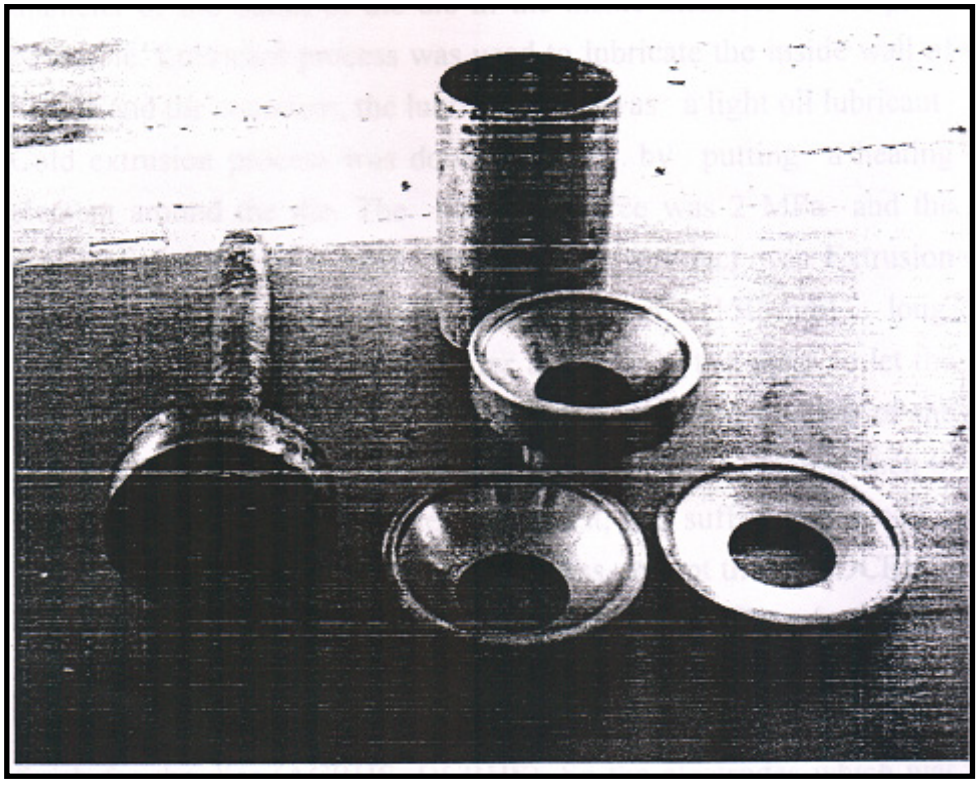


Figure 4.

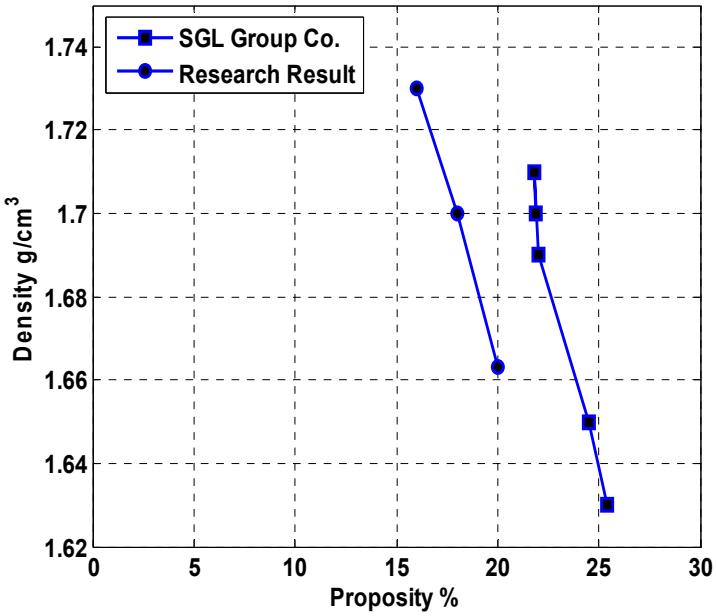


Figure 5.

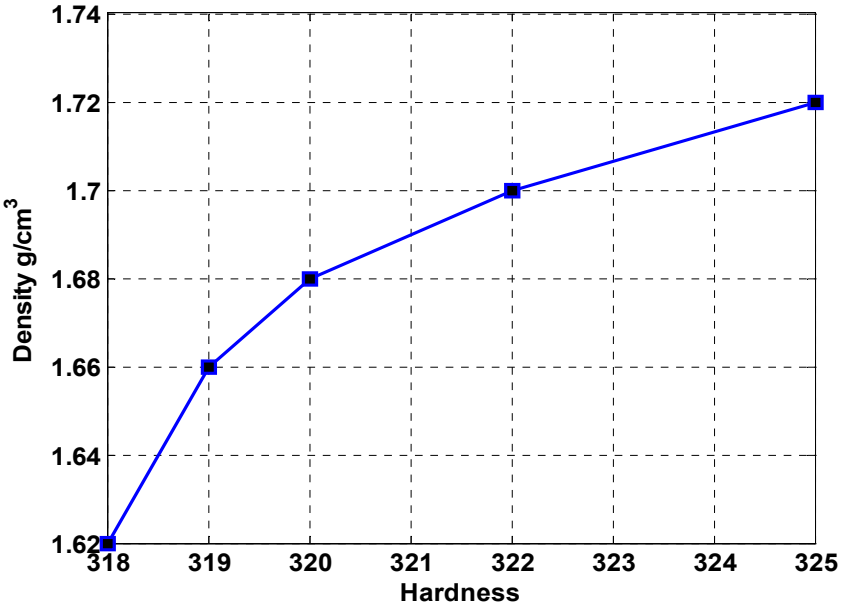


Figure 6.

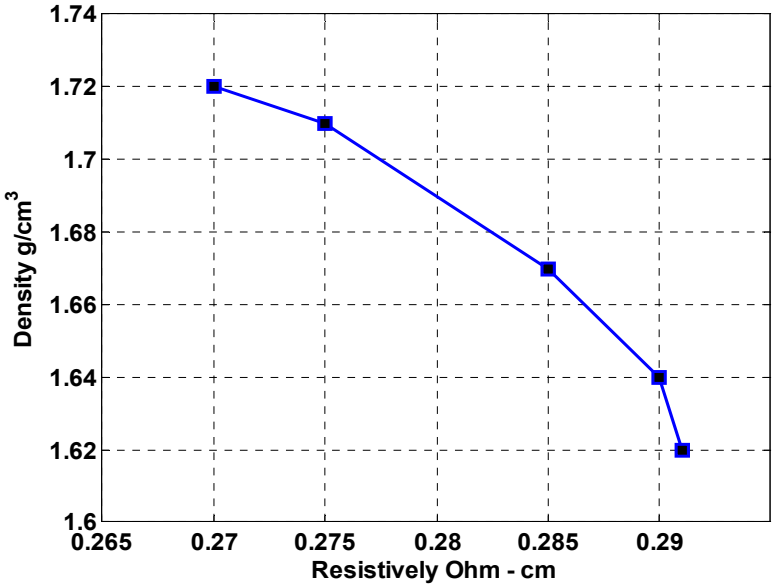


Figure 7.

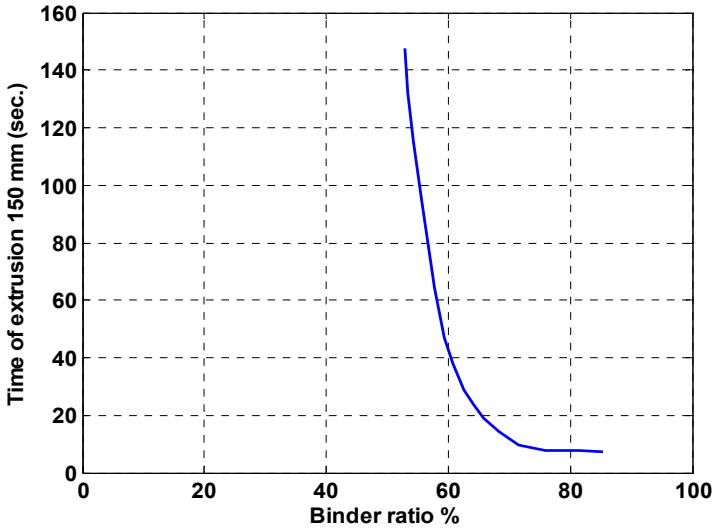


Figure 8.