NIPES

Advances in Engineering Design Technology

Journal homepage: www.nipesjournals.org.ng

Development of Ceramic Candle Filter from Alkaleri Kaolin, Bauchi State, Nigeria

[1]Gadzama Ladi D. M., [2]A.O.Ameh, [2]S.M.Olakunle

[1]Department of Chemical Engineering, Kaduna Polytechnic,
[2]Department of Chemical Engineering, Ahmadu Bello University, Zaria
Corresponding Email: gazama73@gmail.com

Article Info

Received 24 Oct. 2020
Revised 04 Nov. 2020
Accepted 17 Nov. 2020
Available online 07 Dec. 2020

Keywords: *water, ceramics, filter, particles, analysis*

https://doi.org/10.37933/nipes.a/2.2020.4

https://nipesjournals.org.ng

Abstract

Despite the abundant raw materials for the production of candle filters for water filtration, yet candle filters are still imported into the country due to lack of awareness and inadequate engineering equipment need to explore candle filters production from local raw materials, making candle filters expensive beyond the reach of the ordinary man. This work aims at developing an effective ceramic water filter candle from locally available materials: grog, clay, and sawdust. The slip casting method of production was used to form candle shape and subjected to atmospheric drying. The samples/materials were formulated and subjected to physical analysis to determine some parameters and found that the compounded ceramic samples were effective in treatment of water. The filtered water quality was compared with the unfiltered water. The results showed that the filter was very effective in removing suspended particles, coloured dissolved substances, unsavoury odours and taste. The effect of influencing parameters such as firing temperature, clay/sawdust ratio and silver nitrate content were studied. The results generally showed that the clay/sawdust ratio had the greatest effect on the flow rate response. There was a high percentage removal of total dissolved solids of 75% and turbidity removal of 92%. The filters had a hydraulic conductivity of 0.28-0.55 cm/h which showed that the lesser the quantity of sawdust in the filter, the slower the hydraulic conductivity.

1. Introduction

The human body is said to be made up of about 70% water [1]. This shows how important water is to the survival of humans. The importance of water is such that life cannot be sustained beyond a few days, without water supply. Furthermore, the lack of adequate water supply leads to the spread of diseases. Water is used in most human domestic activities and most importantly for drinking, which is a means by which the water level in the human system is maintained. For domestic uses of water, the purity of water is very important, since it has a direct relationship with the health and wellbeing of the individual using the water [2].

In Nigeria, where efforts to improving people’s access to safe drinking water has been marred by social complexes, most of the rural areas and indeed appreciable parts of urban areas do not have access to quality potable drinking water. This usually gives rise to incessant epidemics killing thousands of infants and even adults. It is a common knowledge that poverty-stricken rural communities are still dependent on unsafe drinking water containing a high rate of pathogens that cause epidemic gastrointestinal diseases [3].

Ceramic filter has shown to be a veritable tool in water treatment as the materials are locally available while the method of production is simple. Despite the abundant raw materials for the production of candle filters for water filtration, yet candle filters are still imported into the country due to lack of awareness and inadequate engineering equipment need to explore candle filters production from local raw materials, making candle filters expensive beyond the reach of the ordinary man.

Filtration is the separation of solids from a suspension in a liquid by means of a porous medium or screen which retains the solids and allows the liquid to pass. In general, the pores of the medium are larger than the particles which are to be removed, and the filter works efficiently only after an initial deposit has been trapped in the medium [4]. Filtration technologies are adopted to remove unwanted contaminant, especially suspended solids from surface waters. Filtration has to do with the flow of water through a porous medium. The water is purified through a range of physical, chemical and biological mechanisms [5, 6]. Ceramic filtration is the use of porous ceramic to filter microbes or other contaminants from drinking water. The primary materials used in manufacturing of ceramic candle filters are clay, combustible, and siliceous materials or grog as a non-plastic material used to reduce the shrinkage and control the porosity. The combustible materials are used to increase the porosity of filter media by creating voids within internal structure after the material has been sintered during firing.

The aim of this research is to produce a ceramic candle filter from Alkaleri kaolin in Bauchi State, Nigeria for household water treatment using local materials (sawdust, grog, and kaolin); Carry out physiochemical analysis of the filtered water using the filter candles produced and also the hydraulic conductivity of the filter.

2. Methodology

The lists of materials used in the production of ceramic water filter candles are; Kaolin Sawdust, PVC Adhesive, Sodium Silicate, Sodium Carbonate, Deionized water, Wire mesh sieve, Glass wares, Mortar and pestle, Plaster of Paris (P.O.P) mold, Fettling tools, Cuvette, Reagents, Furnance, Digital weighing balance, pH meter, Mixer, Multiparameter machine.

2.1.Collection of Materials

a. Clay samples

The clay samples used in this study were collected from Alkaleri at Alkaleri Local Government Area in Bauchi State. Also, the plasticity, mechanical, thermal, properties of the clays which are very important in the manufacturing of ceramic water filters were studied under physical analysis before usage for candle filter production.

(a) (b)

Fig 1: Sample of unprocessed (a) and grounded (b) kaolin

b. Hard wood sawdust

The sawdust that was used as a burnout material was obtained from New Market timber shade, Kakuri in Kaduna state. Hard wood sawdust is preferred to soft wood sawdust because according to (6); hardwood sawdust will not bloat as much as sawdust from other woods resulting in more uniform pores and fewer defects in the filter.

Fig 2: Sample of hardwood (sawdust) used as a pore forming agent

c. Adhesive for bonding the plastic container and the filter

PVC adhesive (Top Bond) was used for bonding the ceramic filter. The adhesive was purchased from a plumber shop. It was used because according to the specifications of this adhesive it was suitable for household and industries repair and welds, bonds to all metals, plastic, rubber, wood, ceramic, glass and concrete. In this study, the adhesive was used to bind a ceramic and metal percolator. The adhesive was also not shrinking, waterproof and hardened in less than 3 minutes. These properties were very important for the use of the adhesive in the study.

2.2.Design of Experiment

The experimental design was chosen to study the optimization of three selected parameters: particle size, clay/combustibles ratio and quantity of silver nitrate. Optimization of the yield was carried out based on the experimental matrix defined using respond surface methodology (RSM) Central Composite Design approach (CCD). A 3-level-3-factor CCD was employed in development of ceramic candle filter from locally available materials requiring 20 experimental runs.

2.3. Body Preparation

The raw materials and perforating agents were weighed separately according to their respective composition and mixed well with water to impact green strength in the samples as the preparation is by wet method. The mixture was then mixed using a mixer for thirty minutes to provide a homogeneous mix and obtained in a slurry form. The slurry was shaped into body using plaster of Paris of the desired candle shape by slip casting technique. The samples obtained were sun dried for 21 days. The samples were fired in a furnace between 700- 900^{0}C for eight hours. The fired samples were left to cool and were tested for various properties. Their microstructures were analysed.

2.3.1. Mixing

The materials were mixed using a mixer. Initially, the materials were taken in the bowl and deflocculants (sodium carbonate and sodium silicate) and water were added subsequently to carry out the wet mixing until smooth. After mixing, the slurry was milled in a mixer at constant speed to reduce lumps and particle size of the batch raw materials. This improves the homogeneous mixing and also improves the flow ability of the slip.

2.3.2. Slip Casting

Initially, the density, viscosity and flow ability of the slip were determined by confirmation using specific gravity. The specific gravity for a good slip should be 1.8-2 to get better cast piece and also to avoid having casting defects. Before the slip was poured into the plaster mould, the mould was cleaned using a brush, then talc and left for casting. This was applied on the surface of the slip mould interface to facilitate the smooth releasing of the cast piece from the mould. The slip was poured continuously into the mould to avoid the void formation in the cast piece. Excess slip was drained out after the required thickness formation. After casting, the finishing operation was carried out to remove the excess material and also to smoothen the surface of the cast pieces.

2.3.3. Drying and Firing

The products were initially left for sun drying for seven days. Usually the actual drying schedule of the ceramic candle filters depend on the thickness of the product and the weather at the time of production.

The dried samples were fired in a furnace. The samples were fired at 700, 800 and 900^{0}C respectively. Firing was carried out for 8 hours. The industrial heating cycle was followed for the firing. After firing, the samples were cooled by natural cooling carried out at room temperature.

Fig 3: Dried and fired candle filters

2.3.4. Water sample collection

The waste water sample was collected from a flowing river in Narayi, Kaduna. The sample was collected in a new plastic container which was pre-cleaned by washing with detergents, rinsed in tap water and distilled water before sampling. The containers were rinsed two times with the water sample before being filled with the water. They were then taken to the laboratory and filtered.

Fig 4: The set up for the filtration process

3. Results and Discussion

3.1.Response Surface Methodology (RSM) for Modelling of Candle Filter

Design Expert software package was used for implementing RSM methodology. The input parameters, experimental and predicted values for the response parameters are shown in Table 1.

Table 1: Input parameters for ceramic candle filter production at various runs and responses.

Run	Firing Temperature (^{0}C)	Clay/Sawdust Ratio	Silver Nitrate Solution (g)	Flow rate (mL/h)
1	700	70	0.08	962
2	900	70	0.08	948
3	700	90	0.08	652
4	900	90	0.08	638
5	700	70	0.20	974
6	900	70	0.20	880
7	700	90	0.20	649
8	900	90	0.20	646
9	631	80	0.14	740
10	968	80	0.14	760
11	800	63	0.14	989
12	800	96	0.14	583
13	800	80	0.04	823
14	800	80	0.24	870
15	800	80	0.14	865
16	800	80	0.14	870
17	800	80	0.14	878
18	800	80	0.14	864
19	800	80	0.14	870
20	800	80	0.14	868

The Model F-value of 52.63 implies the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B, A^2, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 57.92 implies the Lack of Fit is significant.

Figure 5 presents the parity plot of experimental values of the responses and predicted values of the model. From the plot of responses against the predicted values of the model, it shows that the values of the predicted as well as that of the actual were close.

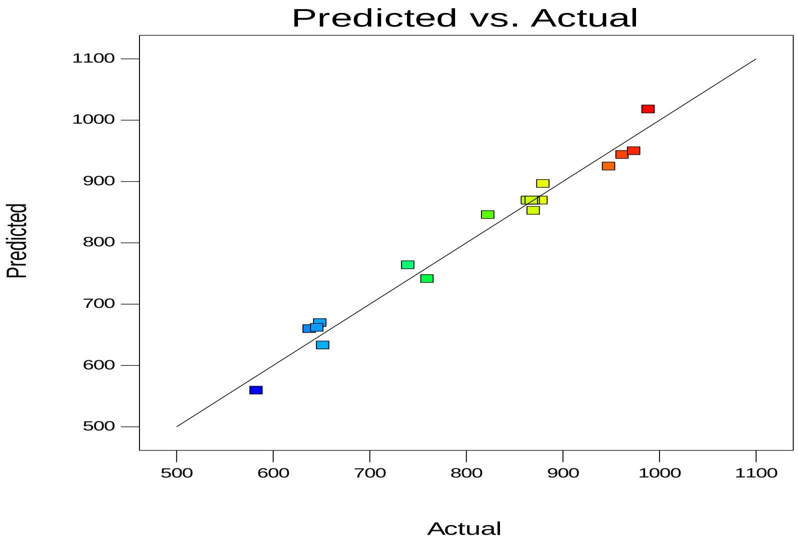

Fig 5: Parity plot of predicted values versus actual (observed) values of flow rate obtained

The response surface 3D plots of flow rate against the firing temperature and clay to sawdust ratio are shown in Figure 6.

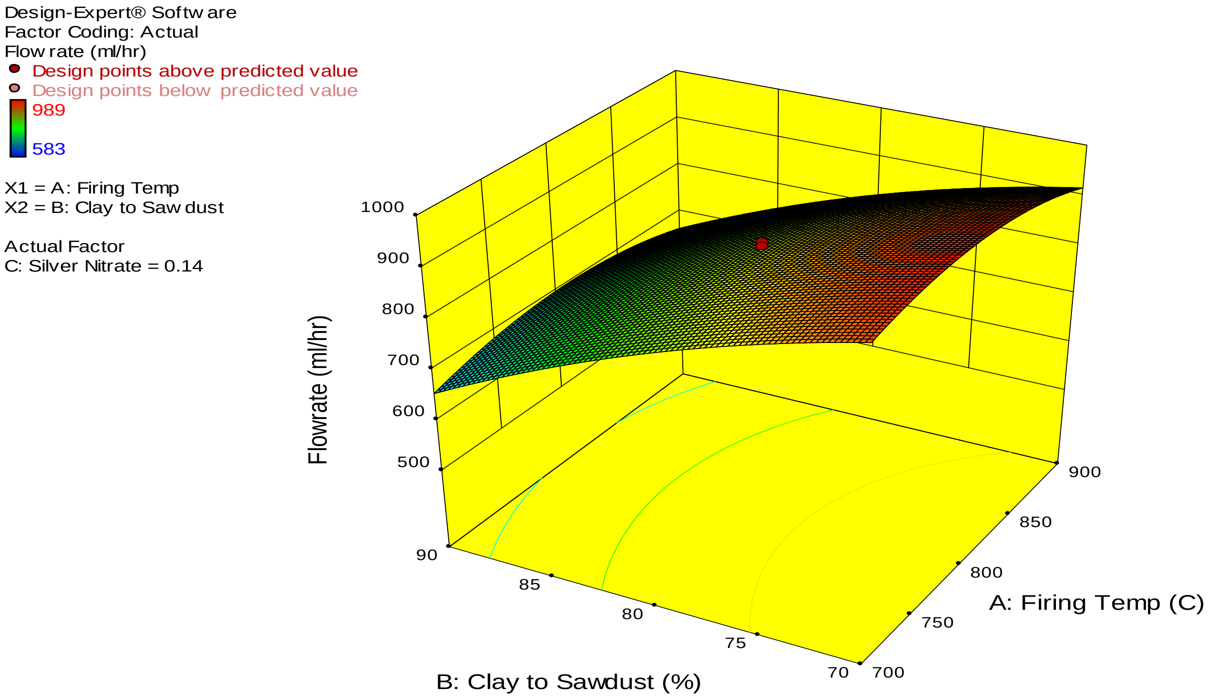

Fig 6: Response surface 3D plot of flow rate versus Firing Temperature and Clay to Sawdust ratio

The model summary for flow rate parameter is shown in Table 2

Table 2: Model summary statistics for the flow rate

Std. Dev.	24.85	R-Squared	0.9793
Mean	817.45	Adj R-Squared	0.9607
C.V.	3.04	Pred R-Squared	0.8408
PRESS		47565.03	
		Adeq Precision	26.233

The Predicted R-Squared of 0.8408 is in reasonable agreement with the adjusted R-Square of 0.9607. Flow rate Equation in terms of Coded Factors is expressed as shown in Equation 1:

$$Flowrate = 869.04 - 6.69A - 136.33B + 2.05C + 11.38AB - 8.62AC + 7.63BC - 41.29A^2 - 28.56B^2 - 7.17C^2 \tag{1}$$

The modelled equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. The high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. Similarly, the final equation in terms of actual factors expressed as Equation 2.

$$Flowrate = -1791.33012 + 5.83011\text{A} + 21.18103\text{B} + 725.07905\text{C} + 1.1375x\ 10^{-2}\text{AB} - 1.43750\text{AC} + 12.70833\text{BC} - 4.1286x\ 10^{-3}A^2 - 0.28558B^2 - 1991.1458C^2 \quad (2)$$

Equation 2 represents the flow rate model in terms of actual factors and can be used to make predictions about the response for given levels factor, as the factors are specified in the original units of each factor.

This equation cannot be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the centre of the design space. The value of regression coefficient, R^2 for the flow rate model was 0.9793 and adjusted R^2 is 0.9607 both indicating the good fitness of the model. Also, the difference between the “Predicted R^2 and Adjusted R^2 is less than 0.2, which indicates the model is in reasonable agreement with the experimental values [7].

Table 3: Result of Physical Analysis for the Ceramic Candle Filter

Run No.	**Linear Shrinkage %**	**Dry weight, M1 (g)**	**Soaked weight, M2 (g)**	**Suspended weight (g), M3**	**Apparent porosity (%)**	**Water of absorption (%)**	**Bulk Density (g/cm^3)**
Run 1	3.89	197.75	298.67	101.25	53.93	54.01	1.00
Run 2	3.95	196.58	250.63	96.35	47.92	47.72	1.09
Run 3	2.19	157.84	290.38	89.40	35.03	27.49	1.39
Run 4	1.88	183.16	270.56	88.16	29.72	40.31	1.80
Run 5	3.95	226.17	300.10	102.34	55.30	83.97	0.99
Run 6	4.00	238.63	295.37	132.37	51.14	51.06	1.00
Run 7	2.50	198.53	260.45	92.70	36.91	23.78	1.31
Run 8	1.88	208.52	248.35	98.38	34.81	20.47	1.45
Run 9	3.23	198.22	305.28	106.78	37.38	31.19	1.14
Run 10	3.13	208.15	281.87	118.22	42.67	34.23	1.17
Run 11	6.1	192.60	270.23	97.33	65.95	87.29	0.79
Run 12	1.82	196.43	265.48	98.45	26.56	19.09	1.80
Run 13	3.23	209.77	284.65	116.89	42.87	34.56	1.15
Run 14	3.16	206.32	283.34	117.67	43.45	32.45	1.16
Run 15	3.18	208.35	280.00	120.56	43.53	34.39	1.18
Run 16	3.23	121.56	140.38	116.35	43.53	32.69	1.27
Run 17	3.21	206.34	285.09	121.45	43.67	33.45	1.15
Run 18	3.85	207.63	286.32	119.38	44.56	33.68	1.15
Run 19	3.16	206.17	288.37	99.55	44.89	35.15	1.18
Run 20	3.82	208.15	250.76	107.38	44.94	39.87	1.11

Linear shrinkage refers to the changes in linear dimensions that has occurred in the filters to be tested after they have been subjected to firing. From the calculations and results of % shrinkage, water of absorption and apparent porosity are increasing with increase in combustible material (sawdust), While bulk density decreased with an increase in combustible materials (sawdust).

Table 4: Optimisation process result summary for the filtered water

Constraints			
Name	**Goal**	**Lower Limit**	**Upper Limit**
A: Firing Temp	is in range	700	900
B: Clay to Sawdust	is in range	70	90
C: Silver Nitrate	is in range	0.08	0.2
Flow rate	Maximize	583	989

Table 5: Total dissolved solids with their percentage removal.

S/No	Ph ---	TDS mg/l	TDS Removal %
1	7.0	118	64.76
2	6.9	120	64.18
3	7.1	78	76.72
4	7.4	82	75.52
5	7.1	115	65.67
6	7.2	112	66.57
7	7.1	85	74.63
8	7.3	88	73.73
9	7.2	108	67.76
10	7.1	103	69.25
11	7.3	143	57.31
12	7.3	68	79.70
13	7.2	108	67.76
14	7.3	110	67.16
15	7.4	100	70.15
16	7.3	108	67.76
17	7.3	106	68.36
18	7.2	107	68.10
19	7.3	110	67.16
20	7.3	109	67.46
Untreated	8.2	335	

Table 5 shows the pH before and after filtration. It is a measure of the hydrogen ion concentration of the water, which indicates whether the water is acidic or alkaline. The result of pH obtained before and after filtration is 8.2 and a range between 6.96 -7.4 respectively, which is within the value of the WHO standard for drinking water (6.50 to 8.50).

Tables 5 shows the values of total dissolved solid (TDS) contained in both the raw and the filtered water samples. High levels of TDS in water may cause objectionable taste and have laxative effect. From the tables, it can be seen that the initial value of TDS in the raw water is 335 mg/L and the value of TDS dropped to the value of between 68-143 mg/L after passing through the ceramic filter. The removal efficiency of the total dissolved solids (TDS) was calculated using this formula:

$$untreated\ water - treated\,\frac{water}{untreated}\,water\ x\ 100 \qquad (3)$$

Hydraulic conductivity is the ease with which a fluid (usually) can move through pore spaces and can be measure using the Darcy Equation. Table 6 shows the hydraulic conductivities of the filters produced.

Table 6: Result of the Hydraulic Conductivity for Ceramic Candle Filter

Run No	Flow rate Q, (mL/h)	Diameter (cm)	Hydraulic Head, H (cm)	Height of candle, hc (cm)	Candle Thickness, tc (cm)	Hydraulic Conductivity, K (cm/h)
Run 1	962	4.8	15.4	14.80	1	0.54
Run 2	948	4.8	15.2	14.60	1	0.55
Run 3	652	4.8	16	15.65	1	0.34
Run 4	638	4.8	16	15.70	1	0.33
Run 5	974	4.8	16	14.60	1	0.51
Run 6	880	4.8	15	14.40	1	0.52
Run 7	649	4.8	16	15.60	1	0.34
Run 8	646	4.8	16	15.70	1	0.33
Run 9	740	4.8	15.5	15.00	1	0.48
Run 10	760	4.8	16	15.50	1	0.47
Run 11	989	4.8	14.5	13.60	1	0.63
Run 12	583	4.8	16.5	16.20	1	0.28
Run 13	823	4.8	15.5	15.00	1	0.46

Run 14	870	4.8	15.8	15.30	1	0.46
Run 15	865	4.8	15.7	15.20	1	0.47
Run 16	870	4.8	15.5	15.00	1	0.48
Run 17	878	4.8	15.6	15.10	1	0.48
Run 18	864	4.8	15.6	15.00	1	0.47
Run 19	870	4.8	15.8	15.30	1	0.46
Run 20	868	4.8	15.7	15.10	1	0.47

The hydraulic conductivity is a measure of the “flowability” of the media and is a function of the properties of both the media and the water. If the media is porous, then the hydraulic conductivity is relatively high, thus allowing water to flow more readily through the media.

Permeability is only a function of the media, whereas hydraulic conductivity is a function of both the media and the water. For ceramic filters, the properties of the water – namely the density and viscosity – are more or less the same, so the primary parameter that influences hydraulic conductivity is permeability k.

4. Conclusion

From the research work done the following conclusions can be drawn:

i) A domestic water candle filter was produced using locally sourced materials (kaolin, sawdust and grog).

ii) Using design expert: results showed firing temperature had no significance on the flowrate (p-value of 0.3544), clay to sawdust ratio was significant on the flow rate (p-value of 0.0001), silver nitrate was not significant on the flow rate (p-value of 0.7718). The optimized firing temperature was 817^{o}C, clay/sawdust ratio was 86, silver nitrate was 0.14g, flow rate was 780mL/h. The desirability was 0.611.

iii) Water absorption increased from 19% to 87%, and porosity increased with increase in particle size, while bulk density decreased from 1.80g/cm^3 to 0.79g/cm^3 as particle size decreased. The hydraulic conductivity was found to be suitable (0.28 – 0.63cm/h). This shows that the water permeated through the filter for some time and was treated before going out of the filter. The filter produced gave an optimized firing temperature of 899.99^{o}C, clay/sawdust ratio was 82.94, silver nitrate was 0.20g, Linear shrinkage was 2.66%, water of absorption was 23.46%, Bulk density is 1.24g/cm^3 and the desirability was 0.75.

References

[1] Dang-I, A. Y. (2010) Clay Filtration of Microbes and Fluoride, African University of Science and Technology (AUST) Abuja, Nigeria

[2] Guy J.B., (2003) “Domestic Water Quality, Service Level and Health” p.1, In: Dang-I, A. Y. (2010) Clay Filtration of Microbes and Fluoride, African University of Science and Technology (AUST), Abuja, Nigeria.

[3] UN World Water Development Report 3: Water in a Changing World; World Water Assessment Programme (WWAP): Perugia, Italy, 2009.

[4] Coulson et.al (2002) “Chemical Engineering Particle Technology and Separation Processes” Vol.2 Fifth Edition

[5] Moshiri. G.A. (1993) Constructed Wetlandsfor Water Quality Improvement, CRC Press, Boca Raton NDWC 1996, Filtration, NDWC, Morgantown, In: Dang-I, A. Y. (2010) Clay Filtration of Microbes and Fluoride, African University of Science and Technology (AUST), Abuja, Nigeria.

[6] Mcallister S. (2005). Analysis and comparison of sustainable water filters. EPD397

[7] Adepoju, T. F. and Olawale, O. (2015) Optimization and Predictive Capability of RSM Using Controllable Variables Azadiracha Indica Oilseeds Extraction Process, Journal of International Journal of Chemistry and Materials Research, 3(1), p. 1-10.