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SUPERPLASTICITY OF BOTTOM ASH REINFORCED ALUMINUM METAL MATRIX COMPOSITE

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Abstract. Superplasticity is a phenomenon that occurs in a material, which in certain conditions, at the strain rate and temperature, can show very high ductility and deformation. Superplasticity declares the strain extension between 100 – 1000 %. The purpose of this research was to obtain a composite material properties of superplasticity in Al 6061 reinforced by bottom ash coal. This research used uniaxial tensile test at high temperature. The variable parameters of this research are temperatures (500, 550, 600 °C) and tensile speed (10^{-5}, 10^{-6}, 10^{-7} m/s). The result of this research is the defined maximum extension of 200% at 600 °C, with tensile speed at 10^{-7} m/sec.

Keywords: aluminum; bottom ash; metal matrix composite; superplasticity.

1. Introduction

Superplasticity is a phenomenon, where in certain conditions, like a strain speed and temperature, the material can shows very high ductility and deformation [1]. Superplasticity properties is very important, because they help to calculate force that is needed in forming process. Al-bottom ash coal material has been produced [2], but the superplasticity properties did not know yet. So, this research is very important to find it.

Application of superplasticity consists in obtainment of the processing conditions that approximate end shape of sample. Additionally, the use of connecting technique of the diffusion bonding with forming superplasticity proposes a processing technique that results in the formation of structural components. These components, which be integrated as a whole, increase rigidity and at the same time approaching the final shape of components, reduce the cost of finishing processing [3].

2. Literature review

Metal matrix composites (MMCs). Metal matrix composites are combinations of two or more materials with one of which is a metal being a matrix. Reinforcements are commonly used are oxide ceramics, carbides and nitrides, whose the main function is to support the most part of applied load. At the same time, a function of the matrix is to possess the reinforcement as a whole and to re-distribute optimally external load to each of reinforcing elements.

The advantage of metal matrix composites over metal materials consists as follows [2]:

1. they are lighter compared to metals (reduced weight by 25 – 30%);
2. toughness to the torque is better;
3. hardness and the wear resistance is better;
4. thermal expansion is lower.

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Superplasticity. Superplasticity is one of the material properties that can be achieved at certain microstructure or specific test conditions. Certain microstructure includes very fine grain size and presence of two-phase structure is necessary to maintain a very fine grain size during testing. Materials, which show superplasticity behavior in certain conditions, have phase boundaries, moving through the stretching material during testing (e.g. at the application of thermal cycling).

There are several factors, influencing the occurrence of material superplasticity, so as strain rate and flow stress.

Strain rate and flow stress. Strain rate is defined as a speed or time required for stretching object from an initial length (L_0) to a final length, expressed as

$$\varepsilon' = d\varepsilon / dt\,. \tag{1}$$

The flow stress is the material property, explaining material resistance to its change, expressed in the form:

$$\sigma = K(\varepsilon^n). \tag{2}$$

Generally, the superplastic material is very sensitive to strain rate and for plastic flow in the solid, it is performed the relationship :

$$\sigma = K\varepsilon'^m\,, \tag{3}$$

where σ is the stress, ε' is the strain rate and m is the strain rate sensitivity. If $m = 1$, then the flow stress is proportional to strain rate and material behaves as a Newton viscous fluid.

Therefore, superplastic material has the characteristic features, connected with great value of m. For tensile specimen with length L, cross-section area A, and work load P, we can obtain:

$$\varepsilon' = -(1/A)dA/dt. \tag{4}$$

By substituting expression (4) into (3), we obtain:

$$dA/dt = (P/K)^{1/m}A^{[1-(1/m)]}. \tag{5}$$

Usually, for most of metals and alloys $m \approx 0.1 - 0.2$ and the rate of change A is very strongly depend on A, but cross-section rate does not depend on A, due to uniformity; then specimen geometry has no effect during deformation. The resistance to shrinkage is highly depends on m, and increases quickly, if $m \geq 0.5$. Let us consider the dependence of flow stress on strain:

$$\sigma = K(\varepsilon^n)\varepsilon'^m. \tag{6}$$

In this case, stability of shrinkage depends on factor $(1 - n - m)/m$, but value of n is usually no high. Constitutive material properties in superplasticity conditions can be used to determine the flow stress [1].

Influence of strain rate on flow properties. Increasing strain rate will improve tensile strength. At the same time, influence strain rate on strength will increase with increasing temperature. Yield strength and flow stress at low plastic strain are very dependent on the strain rate compared with the tensile strength.

Conventional strain rate is expressed using linear strain as

$$\frac{de}{dt} = \frac{d(L-L_0)/L_0}{dt} = \frac{1}{L_0}\frac{dL}{dt} = \frac{v}{L_0}\,. \tag{7}$$

Real strain rate $\frac{d\varepsilon}{dt}$ is defined as

$$\frac{d\varepsilon}{dt} = \frac{d\left[\ln(L/L_0)\right]}{dt} = \frac{1}{L}\frac{dL}{dt} = \frac{v}{L}\,. \tag{8}$$

From (7), (8) the real strain rate is connected with conventional strain rate in the form:

$$\frac{d\varepsilon}{dt} = \frac{L_0}{L}\frac{de}{dt} = \frac{1}{1+e}\frac{de}{dt}\,. \tag{9}$$

Generally, dependence between flow stress and strain rate at constant strain and temperature are defined as follow:

$$\sigma = C\left(\frac{d\varepsilon}{dt}\right)^{m}\Big|_{\varepsilon,T} , \tag{10}$$

where m is the strain rate sensitivity. Power *m* can be obtained from the angular dependence log σ – log ε, but simpler way consists in the testing of the rate change. The value *m* is determined by measuring the change of flow stress due to the change of $\frac{d\varepsilon}{dt}$ at constant values of ε and *T*:

$$m = \left(\frac{\partial \ln \sigma}{\partial \ln \dot{\varepsilon}}\right)_{\varepsilon,T} = \frac{\dot{\varepsilon}}{\sigma}\left(\frac{\partial \sigma}{\partial \dot{\varepsilon}}\right)_{\varepsilon,T} = \frac{\Delta \log \sigma}{\Delta \log \dot{\varepsilon}} . \tag{11}$$

The strain rate sensitivity of a metal at room temperature is very low (< 0.1), but *m* increases when the temperature rises, especially at above point ½ of the absolute melting temperature.

3. Methods

In the experimental study, we selected the following parameters:

1. temperature 500 °C, 550 °C, 600 °C.
2. tensile speed 10^{-5}, 10^{-6}, 10^{-7} (m/s).

Test sample. We used Hot Tensile Test Machine Uniaxial “Shimadzu” with test standard JIZ NO. 1. 220 TYPE 1A, the shape and dimensions of the test specimen are present in Fig. 1.

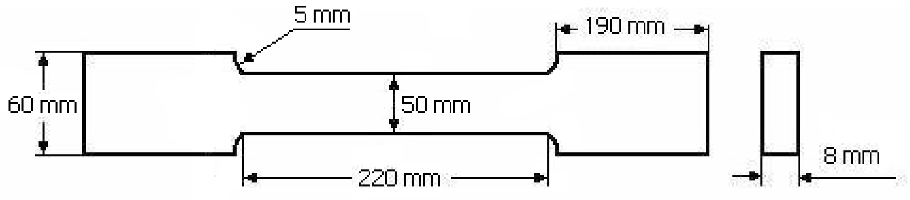

Fig. 1. Shape and sizes of specimen.

Testing Procedure.

1. Measurement of sizes (average diameters) of samples;
2. marking gauge length, namely distance between two points on the test specimen using etcher (cutter) or permanent marker;
3. replacing the specimen with caution in grip Shimadzu testing machine;
4. setting the tensile speed as desired;
5. turn the heater up to the desired temperature and held for some time;
6. start the machine and getting results in the form of graphic load and length;
7. measurement of the sizes of final length and cross-section;
8. marking on the plots of load and length the points of the maximum and fracture;
9. combining the plots of load and length transform them to stress-strain plot.

Figure 2 presents a flow chart for the experiment.

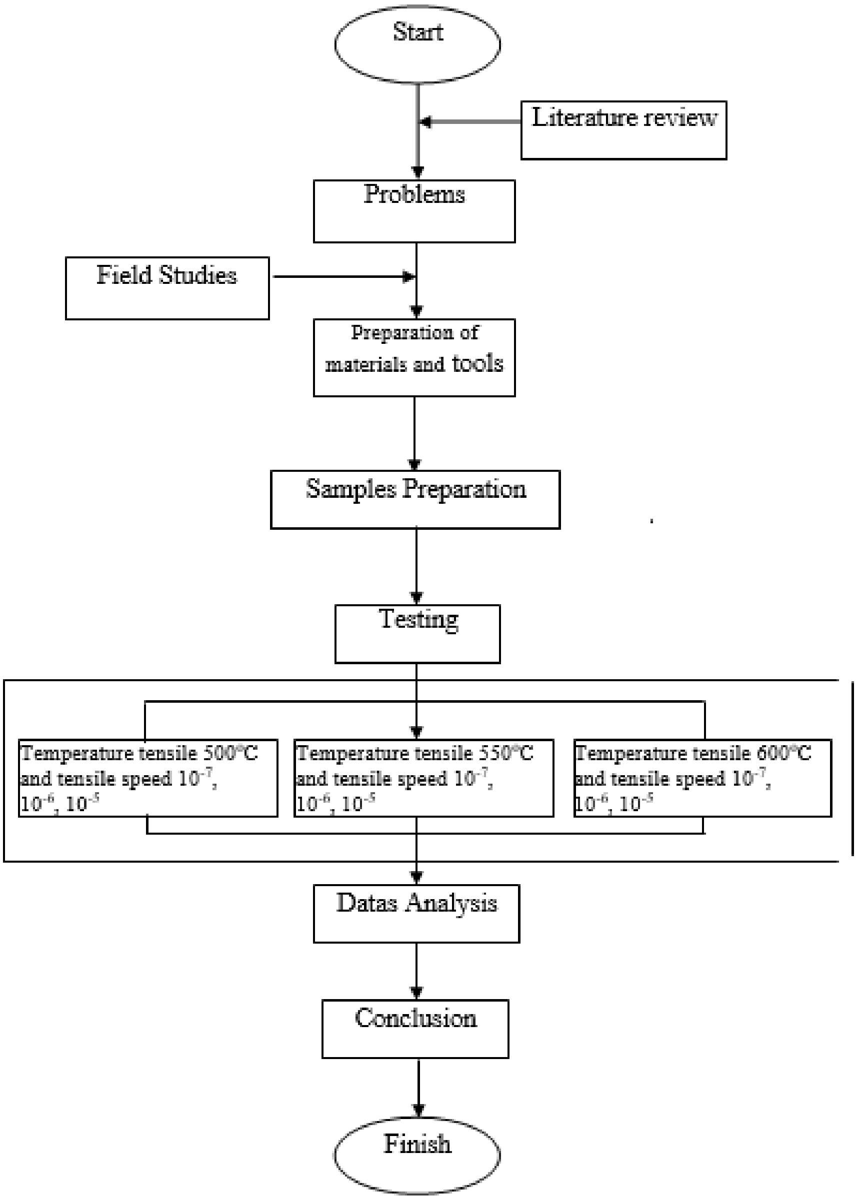

Fig. 2. Flowchart of experiment.

4. Result and Analysis

Tables 1 – 3 present results of hot tensile tests at temperatures of 500, 550 and 600 °C, and speeds of 10^{-5}, 10^{-6}, 10^{-7} m/s..

Table 1. Test results at temperature of 500 °C, and speeds of 10^{-5}, 10^{-6}, 10^{-7} m/s.

Parameter	Speed Tensile (m/s)								
	10^{-5}			10^{-6}			10^{-7}		
	A1	A2	A3	B1	B2	B3	C1	C2	C3
Maximum load (P_{max}), kgF	2035	2033	2036	2040	2039	2041	2047	2044	2046
Final length (l_f), mm	637	636	638	640	640	641	645	647	650

Final thickness, mm	6.5	6.4	6.5	6.4	6.3	6.2	6.3	6.2	6.3
Final wide, mm	21.25	21.61	21.22	21.48	21.82	22.14	21.65	21.93	21.48
Final area (A_f), mm^2	138.125	128.304	137.93	137.472	137.466	137.268	136.395	135.966	135.324
Tensile strength (σ_{TS}), kgF/mm²	5.087	5.082	5.090	5.100	5.097	5.102	5.117	5.110	5.115
Strain (ε), %	189.545	189.091	190.000	190.909	190.909	191.364	193.182	194.091	195.455

Table 2. Test results at temperature of 550 °C, and speeds of 10^{-5}, 10^{-6}, 10^{-7} m/s.

Parameter	Speed Tensile (m/s)								
	10^{-5}			10^{-6}			10^{-7}		
	A1	A2	A3	B1	B2	B3	C1	C2	C3
Maximum load (P_{max}), kgF	2040	2038	2041	2045	2044	2046	2052	2049	2051
Final length (l_f), mm	644	646	645	649	648	650	653	652	655
Final thickness, mm	5.9	5.8	5.7	5.8	5.6	5.7	5.7	5.6	5.5
Final wide, mm	23.16	23.48	23.93	23.37	24.25	23.75	23.64	24.10	24.42
Final area (A_f), mm^2	136.644	136.184	136.401	135.546	135.800	135.375	134.748	134.960	134.31
Tensile strength (σ_{TS}), kgF/mm²	5.100	5.095	5.102	5.112	5.110	5.115	5.130	5.122	5.127
Strain (ε), %	192.727	193.636	193.182	195.000	194.545	195.455	196.818	196.364	197.727

Table 3. Test results at temperature of 600 °C, and speeds of 10^{-5}, 10^{-6}, 10^{-7} m/s.

Parameter	Speed Tensile (m/s)								
	10^{-5}			10^{-6}			10^{-7}		
	A1	A2	A3	B1	B2	B3	C1	C2	C3
Maximum load (P_{max}), kgF	2045	2043	2046	2050	2049	2051	2057	2054	2056
Final length (l_f), mm	649	651	650	655	653	655	658	657	660
Final thickness, mm	5.2	5.2	5.1	5.1	5.0	5.0	4.9	4.8	4.7
Final wide, mm	26.07	25.99	26.54	265.34	26.95	26.87	27.29	27.90	28.36
Final area (A_f), mm^2	135.564	135.148	135.354	134.334	134.350	134.750	133.751	133.920	133.292
Tensile strength (σ_{TS}), kgF/mm^2	5.112	5.107	5.115	5.125	5.122	5.127	5.142	5.135	5.140
Strain (ε), %	195.000	195.909	195.455	197.727	196.818	197.727	199.091	198.636	200.000

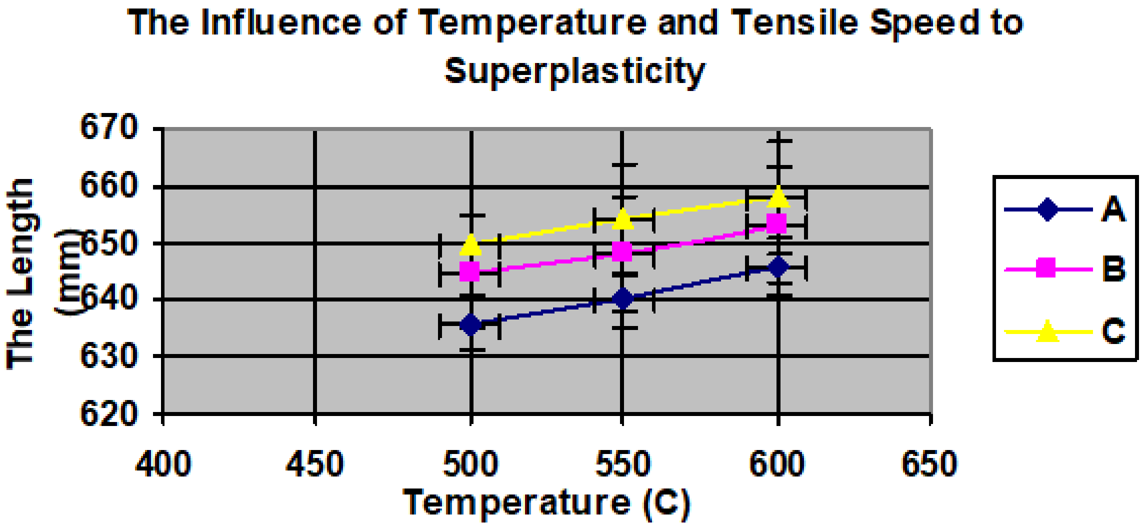

Fig. 3. Influence of temperature and tensile speed on length; tensile speed 10^{-5} m/s (A); 10^{-6} m/s (B); 10^{-7} m/s (C).

Temperature influence on length. Temperature greatly affects the properties of materials, especially the increase in ductility. Increased elasticity is due to the reduction of dislocations as result of the rearrangement of atoms (recrystallization). The effect of temperature can be seen in Fig. 3, where higher temperature corresponds to the obtained higher extension. In the temperature range considered, superplasticity has occurred.

Influence of tensile speed on length. In the case of tensile rate, the slower tensile corresponds to the greater extension because the lower tensile rate provides opportunities for the material to slip or shear gradually. The influence of the tensile speed can be seen in Fig. 3.

5. Conclusion

1. The higher temperature leads to the longer length. The slower tensile speed causes the longer length. So, we obtained the maximum extension is 200 % at temperature of 600 °C with tensile speed 10^{-7}.
2. With maximum extension of 200% in this material, the superplasticity condition has been obtained.

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