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Characteristics Of Heat Expansion Of Aluminum Composites Reinforced Al_2O_3 Particles

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Abstract – Aluminum oxide particles (Al_2O_3) are ceramic particles which have a smaller thermal expansion than aluminum. Aluminum as matrix, which is a relatively low-cost metal, has good compatibility when reinforced with ceramic particles. By adding Al_2O_3 particles into aluminum to become a metal matrix composite material. Varying the amount of Al_2O_3 particles was carried out to determine the effect of adding Al_2O_3 on the coefficient of linear thermal expansion of metal matrix composite. Aluminum matrix composite (AMC) specimens reinforced with Al_2O_3 particles, produced by casting technique preceded by smelting with mixing called compocasting technique with variations of reinforcing particles of 5%, 10%, 15%. The tests carried out were the thermal expansion test of the AMC material and the metallographic test to determine the distribution of the AMC reinforcing particles. Adding Al_2O_3 can reduce the thermal expansion of the resulting composite. The measurement results of the technique linear thermal expansion of the AMC resulting from the compocasting process are smaller than the aluminum matrix thermal expansion. The decrease in the technique linear thermal expansion was greater with increasing composition of Al_2O_3 in the AMC. The lowest value of the coefficient of technique linear thermal expansion α(27^0C, 210^0C) occurs in AMC with a content of 15% Al_2O_3, which is equal to 6.6 E-6/^{0}C.

Keywords – composite; aluminum; thermal expansion

I. Introduction

Metal matrix composites are suitable for use in heat and friction resistant materials such as pistons, light metal bearings, gas turbine blades and other engine elements. Materials used at high temperatures must have good conductivity, be resistant to expansion, resist oxidation, when accompanied by a load must have resistance to deformation, good strength, stiffness, low density, long fatigue life, and wear resistance and what is also important easy in the production process. These things make composite materials with a metal matrix (metal matrix composite / MMC) a concern and continue to be researched and always developed [1].

Aluminum has attracted a lot of attention for MMC matrix materials because of its advantageous properties: light weight, hardness and strength for applications in various fields. Compared with alternative materials that can be considered in the same type of application, aluminum matrix composite materials have many advantages, such as high strength, rigidity, corrosion resistance and wear resistance and can be manufactured by common equipment. In the use of aluminum as a matrix in MMC in pure form or in alloys. Aluminum alloys are of greater interest because apart from being a matrix, precipitates will also be formed by the alloying elements [2]. The combination of light, inexpensive, and relatively good mechanical properties makes aluminum good for use as a matrix for AMC.

The microstructure of the alloy is modified and compensated for the defects of the alloy by adding a reinforcing phase. The performance effect of the reinforcing phase on the metal matrix composite material mainly includes the following factors: the state of the interface between the reinforcing phase and the matrix, the reaction between the matrix and the reinforcing phase, the wettability of the reinforcing phase by the matrix, and the required performance of the aluminum matrix composite material. Particulate reinforced aluminum matrix composites have been studied extensively for their low density, high strength-to-weight ratio, superior physical properties, high rigidity, good wear resistance and other mechanical properties, and relatively low cost [3].

Ceramic particles have less thermal expansion than metals and are more resistant to friction. Thus inserting ceramic particles into the metal can reduce the composite thermal expansion. Aluminum matrix with a relatively low price has good compatibility when reinforced with ceramic particles such as silicon carbide (SiC) or aluminum oxide Al_2O_3 [4]. Among the techniques for joining MMC components, compaction and casting processes are the most widely used processes due to their simplicity, economy, and flexibility. The production cost of MMC casting is even lower, namely by using a stirring technique using a stirrer blade (stir mixing) to mix the particles as MMC reinforcement followed by pouring into the mold which is called the compocasting technique, this has attracted more attention from the industry [5].

The increasing demand for lightweight materials with high specific strength in the automotive and aerospace industries is accelerating the development and use of MMC. The use of industrial materials for friction components and at high temperatures must be resistant to the effects of high temperatures and moreover operating at high loads must be resistant to deformation such as those used in high-pressure turbine blades, bearings and combustion engine pistons. The MMC material from this study has the potential to meet this demand. The engineering materials resulting from the process are characterized in order to obtain the material properties related to their application. MMC product materials that are used at high temperatures or large shock temperatures need to be characterized for their coefficient of thermal expansion. The characterization concerning these aspects of temperature in the use of solid material products can be carried out with a measuring device for the coefficient of thermal expansion which is often called a dilatometer. From the description above, a problem can be drawn regarding the thermal expansion characteristics of aluminum oxide reinforced aluminum composites.

In materials science, there is a relationship between microstructure, properties and ways of processing. By looking at the relationship between the three, material performance can be planned [6]. Various variables produce different characters in AMC such as matrix type, reinforcement type, reinforcement percentage, interface state, type of metallurgical process. In this study the matrix used was Aluminum 6060 alloy, the added particles were aluminum oxide particles (Al_2O_3) with a composition of 5 %, 10%, 15%, the metallurgical process was compocasting at a stirring speed of 300 rpm followed by casting in a metal mold. With this process design and its variables, data on the properties of the new AMC material are obtained. These data are very important for the development of science because there are still limited data on the microstructure and properties of AMC compared to monolithic materials such as metals and their alloys.

II. Material And Experimental Procedures

The manufacture of aluminum matrix composites reinforced with aluminum oxide particles was carried out using the compocasting technique. Variation of reinforcing composition in the manufacture of aluminum matrix composites reinforced with aluminum oxide particles by means of compocasting technique is applied to obtain MMC which is then characterized by the coefficient of elongation expansion. Aluminum alloy 6060 is used as the metal matrix. This aluminum alloy has a density of 2.7 g/cm^3. Aluminum oxide particles (100 µm white Al_2O_3) with a density of 3.98 g/cm^3 were used to produce the Al alloy-Al_2O_3 composite. The experimental setup used in this study was relatively simple, consisting of a crucible-type aluminum smelting furnace and a stirring apparatus (Fig. 1). A stainless steel four-blade stirrer is threaded onto the stirrer shaft. The stirrer blade is used to move the Al_2O_3 particles in the slurry. A 10 mm diameter stainless steel shaft is inserted into the crucible from the hole at the top of the furnace. The agitator shaft is connected to a speed-adjustable motor. The temperature of the metal in the crucible during melting is measured with a type K thermocouple.

Fig. 1. Aluminum smelt.

Processing of the aluminum alloy-Al_2O_3 composite was obtained by melting 1053 grams of aluminum alloy in a crucible, with predictions of 5% loss of aluminum alloy due to evaporation, combustion and corrosion of the slurry surface. While 50 grams of aluminum oxide particles were prepared. So that the Al_2O_3 particles can be easily immersed in molten aluminum, the particles are wrapped in aluminum foil (figure 2). The crucible which has been filled with aluminum is put into the furnace, and heated at 750^{0}C until the aluminum is completely melted. After the aluminum has melted, the furnace is turned off so that the temperature drops to 700^{0}C; the temperature of the molten aluminum is monitored by a type K thermocouple placed at a depth of 10 – 15 mm from the molten aluminum surface. Before to the next step, the melted surface is cleaned of impurities by screening with the aid of a steel bar. The stirrer is heated by positioning it above the crucible in the furnace for about 20 seconds so that any water or oil impurities that are still attached to it evaporate or burn. When the melt temperature reaches 700^{0}C, the stirrer is lowered into the melt and stirred at 300 rpm.

Particles that have been wrapped in aluminum foil (figure 2) are immersed in the slurry when the slurry temperature is 700^{0}C. The particles were stirred for 2 minutes to ensure a complete mixing in the crucible. At the end of the movement, the molten metal in the crucible is poured into a metallic mold at 240^{0}C with a diameter of 30 mm and a length of 170 mm by gravity. When the desired amount of reinforcement is 10% and 15%, the reinforcing particles are subjected to the same treatment. After adding the reinforcing particles in the first step, they were driven for about 2 minutes, then the reinforcing particles were added for the second stage and driven again for 2 minutes and so on. The mold is then placed at room temperature, and after cooling the AMC is removed from the mold. The castings are then machined to specimen size of 5 mm x 5 mm x 50 mm

Fig. 2. Al_2O_3 particles wrapped in aluminum foil

The coefficient of linear thermal expansion AMC is measured with a dilatometer, the image of the dilatometer is shown in Figure 3. The construction is made based on the working principle to be applied. The specimen is placed in a controlled electric furnace and the temperature is known by means of a thermocouple. The specimen will increase in length when exposed to heat in the furnace. Increasing the length of spesimen will push the push rod which is then passed on to the micrometer. The increase in the length of specimen can be seen from the measurements shown by the micrometer. The material for the dilatometer to measure metal expansion is made of ceramic with a small coefficient of expansion so that the expansion of the device is small and can be calibrated more easily. The material used in the dilatometer furnace is compacted white aluminum oxide added with 5% clay as an adhesive. The dilatometer materials are mixed by adding water to make them stick together and then pressed under pressure, then heated to remove the water content. The dilatometer holder is made of angled steel for a stronger construction.

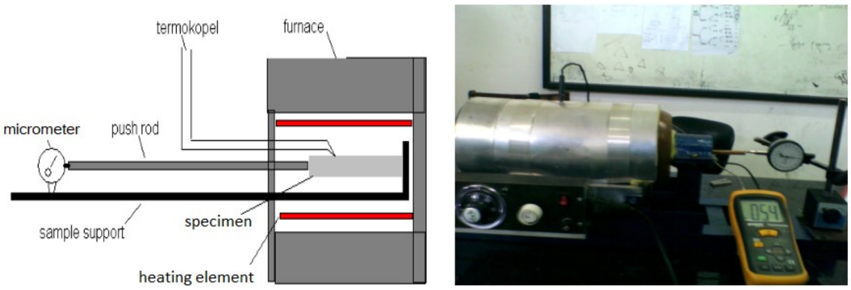

Fig. 3. Dilatometer

The measuring principle of the dilatometer is that the increase in the length of the specimen due to the increase in temperature is mechanically transmitted to the micrometer. The transmission is carried out by a push rod made from the same material as the support for the specimen. The change shown on the micrometer is not the actual change in length, this is caused by the push rod and the support of the test object which also expands. It is also influenced by the speed of heating and the surrounding atmosphere. To obtain changes in the length of the actual test object (corrected or often called absolute) measurement calibration is required [7]. Calibration is carried out under the same measurement conditions as the measurement conditions of the test object and is carried out using a test object whose coefficient of thermal expansion is known (referred to as a standard material). With this calibration, a corrected observation table can be made with "(1)."

$$\left(\frac{\Delta L}{L_0}\right)_{correction} = \left(\frac{\Delta L}{L_0}\right)_{standart\ material} - \left(\frac{\Delta L}{L_0}\right)_{standart\ material\ measurement}$$

$$\left(\frac{\Delta L}{L_0}\right)_{corrected} = \left(\frac{\Delta L}{L_0}\right)_{measurement} + \left(\frac{\Delta L}{L_0}\right)_{correction} \qquad (1)$$

Where:

$\left(\frac{\Delta L}{L_0}\right)_{correction}$ = correction of relative length expansion

$\left(\frac{\Delta L}{L_0}\right)_{standart\ material}$ = relative length expansion of the standard material

$\left(\frac{\Delta L}{L_0}\right)_{standart\ material\ measurement}$ = relative length expansion of the standard material when measured

$\left(\frac{\Delta L}{L_0}\right)_{measurement}$ = relative length expansion of specimen when measured

$\left(\frac{\Delta L}{L_0}\right)_{corrected}$ = corrected relative length expansion of specimen

So that the technical linear thermal expansion of the specimen is obtained by "(2)" [7].

$$\alpha(T_1, T_2) = \frac{\left[\left(\frac{\Delta L}{L_0}\right)_{T2\ corrected} - \left(\frac{\Delta L}{L_0}\right)_{T1\ corrected}\right]}{(T_2 - T_1)} \qquad (2)$$

Where:

$\alpha(T_1, T_2)$ = technical linear thermal expansion coefficient between T_1 to T_2

T_1 = measuring temperature 1

T_2 = measuring temperature 2, $T_2 > T_1$

The coefficient of physical linear thermal expansion "(3)," which is the first derivative of the corrected relative length increase with temperature:

$$\alpha(T) = \frac{d\left(\frac{\Delta L}{L_0}\right)_{corrected}}{dT} \quad (3)$$

III. RESULT AND DISCUSSION

AMC reinforced Al_2O_3 with various particle compositions has been produced by compocasting technique. The microstructure of the aluminum alloy is shown in Figure 4(a), while the aluminum metal matrix composite with 15% aluminum oxide reinforcing particles is shown in Figure 4(d). An even distribution of reinforcing particles can be seen in Figure 4 (d). When agitation is used to mix the aluminum oxide and molten aluminum particles, the collisions between the solid and molten phase particles will result in a uniform distribution of the particles in the molten aluminum. Longer mixing results in an even distribution of the particles. The same microstructure is shown in the composite specimen containing 10% and 5% reinforcing particles but the particle distribution is more tenuous.

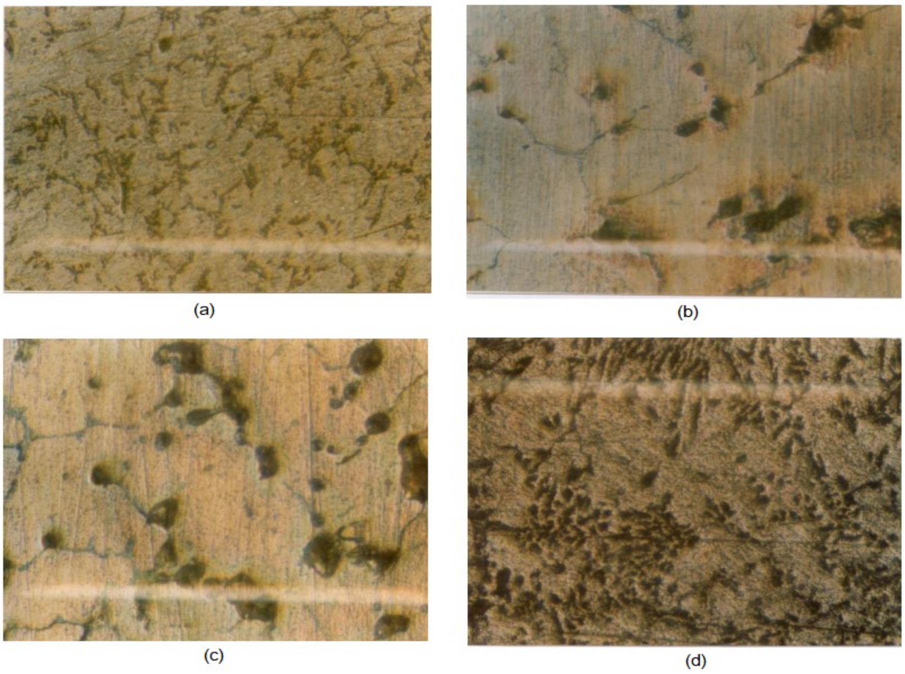

Fig. 4. Micro structure : (a) Al alloy (b) Al alloy-5% Al_2O_3 particles (c) Al alloy-10% Al_2O_3 particles (d) Al alloy-15% Al_2O_3 particles .

Calibration of the linear thermal expansion measuring device (dilatometers) carried out in order to obtain the actual length increase value, namely the absolute length increase or often called the corrected length increase of the material being tested. When the composite expansion test is carried out, there is also an expansion in the push rod, sample support and other parts, it is necessary to correct the measurements.

TABLE I. CORRECTION OF RELATIVE LENGTH EXPANSION

No	***Temperatur (^0C)***	***ΔL/Lo standart material (E-3)***	***Standart material measurement ΔL (micro meter)***	***ΔL/Lo standart material measurement (E-3)***	***ΔL/Lo correction (E-3)***
1	27	0.061	0	0	0.061
2	40	0.1294	0	0	0.1294
3	50	0.2182	0	0	0.2182
4	60	0.3074	0	0	0.3074
5	70	0.397	0	0	0.397
6	80	0.447	0	0	0.447
7	90	0.5174	0	0	0.5174
8	100	0.5682	0	0	0.5682
9	110	0.6194	3	0.06	0.5594
10	120	0.691	3	0.06	0.631
11	130	0.743	7	0.14	0.603
12	140	0.7954	7	0.14	0.6554
13	150	0.8482	12	0.24	0.6082
14	160	0.9014	12	0.24	0.6614
15	170	0.955	21	0.42	0.535
16	180	1.009	21	0.42	0.589
17	190	1.0634	32	0.64	0.4234
18	200	1.1182	32	0.64	0.4782
19	210	1.1734	45	0.9	0.2734

Corrections are made by measuring the increase in length of a standard material specimen whose absolute length increase is known. The standard material for the dilatometer made is aluminum oxide rod, this standard specimen is tested with another dilatometer that has been calibrated to obtain the absolute increase in length. Table 1 is a correction number for dilatometer measurements. The corrected length increase table is used to obtain the corrected composite length increase value, the following (table 2) is one of the measurement results:

TABLE II. AN EXAMPLE OF CALCULATING THE CORRECTED 5% AL_2O_3 COMPOSITE LENGTH INCREASE

no	***Temperatur (^0C)***	***ΔL measurement (micron)***	***ΔL/Lo measurement (E-3)***	***ΔL/Lo correction (E-3)***	***ΔL/Lo corrected (E-3)***	***α(30-210) E-6/^{0}C***
1	27	0	0	0.061	0.061	0.013958
2	40	0	0	0.1294	0.1294	
3	50	0	0	0.2182	0.2182	
4	60	1	0.02	0.3074	0.3274	
5	70	5	0.1	0.397	0.497	
6	80	7	0.14	0.447	0.587	
7	90	11	0.22	0.5174	0.7374	
8	100	17	0.34	0.5682	0.9082	
9	110	22	0.44	0.5594	0.9994	
10	120	30	0.6	0.631	1.231	
11	130	38	0.76	0.603	1.363	
12	140	45	0.9	0.6554	1.5554	

13	150	56	1.12	0.6082	1.7282	
14	160	78	1.56	0.6614	2.2214	
15	170	82	1.64	0.535	2.175	
16	180	93	1.86	0.589	2.449	
17	190	100	2	0.4234	2.4234	
18	200	105	2.1	0.4782	2.5782	
19	210	115	2.3	0.2734	2.5734	

The coefficient of linear thermal expansion of the composite technique between 27^0C to 210^0C is obtained by “(4).”

$$\alpha(27^0, 210^0) = \frac{\left[\left(\frac{\Delta L}{L_0}\right)_{210\ corrected} - \left(\frac{\Delta L}{L_0}\right)_{27\ corrected}\right]}{(210-27)}$$

The complete results of the techniques coefficient of linear thermal expansion of aluminum matrix and aluminum matrix composite are in table 3.

TABLE III. COEFFICIENT OF THERMAL EXPANSION OF ALUMINUM ALLOY AND ALUMINUM MATRIX COMPOSITE

No	**% Al_2O_3**	**$\alpha(27^0C,210^0C)$ (E-3/^{0}C)**	**Everage of $\alpha(27^0C,210^0C)$ (E-3/^{0}C)**
1	0	0.018069	0.01981
	0	0.021291	
	0	0.020069	
2	5	0.013624	0.013921
	5	0.013958	
	5	0.01418	
3	10	0.00918	0.011032
	10	0.011958	
	10	0.011958	
4	15	0.006402	0.006550
	15	0.006736	
	15	0.006513	

From table 3, it is obtained that the coefficient of linear thermal expansion of aluminum is the largest, 19.8E-6/^{0}C. Meanwhile, the coefficient of thermal expansion of pure aluminum based on a reference is 21.5 E-6/^{0}C to 27.9 E-6/^{0}C [8]. As can be seen in Figure 4, the addition of Al_2O_3 ceramic particles reduces the thermal expansion of the aluminum matrix composite.

TABLE IV. THERMAL EXPANSION OF CERAMIC MATERIALS AND ALUMINUM ALLOYS [9]

Reinforcement particle and alloy	***Thermal expansion* (10^{-6}/^{0}C)**
SiC	4,8
Al_2O_3	7,5
A 2014	23
A 6061	22

Ceramic particles have a smaller coefficient of thermal expansion than aluminum alloy shown in Table 4, so their presence in the aluminum matrix reduces the coefficient of thermal expansion of the composite. The coefficient of thermal expansion of metal composite reinforced with Al_2O_3 particles is 13.9 E-6/^{0}C for 5% particle reinforcement, 11 E-6/^{0}C for 10% particle reinforcement, and 6.6 E-6 /^{0}C for 15% particle reinforcement. This shows the trend of decreasing the coefficient of thermal expansion of metal matrix composites with increasing amount of Al_2O_3 particles in it.

In the manufacture of aluminum matrix composites using the stir casting technique, porosity is a major problem. With an increase in the amout of reinforcing particles, the porosity increases by entrapping gases between the particles. Gases are also sucked in and trapped during mixing with agitation [10]. Porosity plays an important role in expansion. Hollow materials have a smaller coefficient of expansion than solid materials, this is because there is no mass to expand in the cavity so that the total expansion of the material becomes smaller. The more reinforcing particles are included in the composite matrix with the stir casting process, so that the greater the amount of porosity in the composite, and the coefficient of thermal expansion also decreases. Both ceramic particles and porosity play a role in reducing the coefficient of thermal expansion in the composite [11].

IV. CONCLUSION

The coefficient of linear thermal expansion of the aluminum matrix composite reinforced with Al_2O_3 particles is smaller than the coefficient of linear thermal expansion of the aluminum alloy. The coefficient of linear thermal expansion of the aluminum matrix composite reinforced by Al_2O_3 particles gets smaller with the addition of Al_2O_3 particles in the composite, the smallest coefficient of linear thermal expansion technique in this study is $\alpha(27^0C, 210^0C) = 6.6$ E-6/^{0}C owned by AMC with 15 % aluminum oxide.

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