International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 23 (2015) pp 43752-43757
© Research India Publications. http://www.ripublication.com

Effect of Phosphorous, Titanium-Boron and Titanium on Thermal Properties of Hypereutectic Aluminium-Silicon Alloys

B. M. Angadi

Mechanical Engineering Department B.L.D.E.A'S V P Dr. P.G. H. C.E.T Vijayapur, Karnataka, India

A. Chennakesava Reddy

Mechanical Engineering Department JNTU Hyderabad, A.P, India

V. V. Katti

Principal, VDRIT, Haliyal, Karnataka, India

V.V. Nagathan

Mechanical Engineering Department B.L.D.E.A'S V P Dr. P.G. H. C.E.T Vijayapur, Karnataka, India

S. A. Kori

Mechanical Engineering Department Basaweshwar engineering college Bagalkot, Karnataka, India

ABSTRACT

Experiments are carried out to analyze the effect of Phosphorous (P), Titanium-Boron (TiB) and Titanium (Ti) on thermal properties of hypereutectic Aluminium-Silicon (Al-Si) alloys by a new rapid transient method for the determination of thermal properties like thermal diffusivity, specific heat and thermal conductivity of hypereutectic Aluminium-Silicon alloys. The present transient method is based on the application of constant heat flux on top surface of circular cylindrical hypereutectic Aluminium-Silicon specimens that is insulated on all other surfaces. The method is applied to determine the thermal properties of hypereutectic Al-Si alloys such as Al-13Si, Al-14Si, Al-15Si, Al-17Si and Al-20Si with and without the addition of phosphorous, Titanium Boron and Titanium. Results clearly indicate that thermal properties such as thermal diffusivity, specific heat and thermal conductivity decreases with increase in Si content in hypereutectic Al-Si alloys and also with the addition of phosphorous, Titanium Boron and Titanium.

Keywords: Hypereutectic Al-Si alloys, Phosphorous, Titanium-Boron, Titanium, Transient method, Thermal properties.

Introduction

Aluminium is considered to be a futuristic material because of its advantages such as light weight, excellent castability physical and mechanical properties. Among the aluminium alloys, hypereutectic Al-Si alloys are most widely used in aerospace and transportation due to their excellent mechanical, thermal and casting properties. The Al-Si alloys that contain more than 12 wt % silicon are known as hypereutectic alloys and normally consist of the primary silicon phase in the eutectic matrix. More attention are paid to the hypereutectic Al-Si alloys with addition of phosphorous, Titanium Boron and Titanium than conventional as cast hypereutectic Al-Si alloys for automotive applications and piston production because of their attractive combination of low coefficient of thermal expansion, high elastic modulus, high wear resistance, lower density, higher thermal stability, corrosion resistance, good thermal conductivity and machinability.

The more comprehensive data base goes hand-in hand with a more rapid method of measuring thermal properties. Thermal properties of hypereutectic Al-Si alloys can be described by three physical quantities; thermal conductivity (K), thermal diffusivity (α) & specific heat (C). Thermal conductivity is essentially a coefficient of static heat transfer and thermal diffusivity is a coefficient of transient heat transfer. The three quantities are related by the equation.

$$K=\rho\, C\, \alpha \qquad (1)$$

Where, ρ is the density.

Main aim of this research work is to study the effect of Phosphorous, Titanium boron and Titanium on thermal properties of hypereutectic Al-Si alloys by a transient method of measuring thermal diffusivity and thermal conductivity and present suitable values. This method determines thermal diffusivity directly and calculates thermal conductivity by using equation (1).

2.0 THEORY

The measurement of thermal properties is done with a constant heat flux at the top of specimen, which is insulated by a insulating material all around the specimen. The measurement of temperature at the base of the specimen is made for various times after introduction of the constant heat flux at its top surface as shown in fig 1. The theory is discussed for the one dimensional (1-D) single slab.

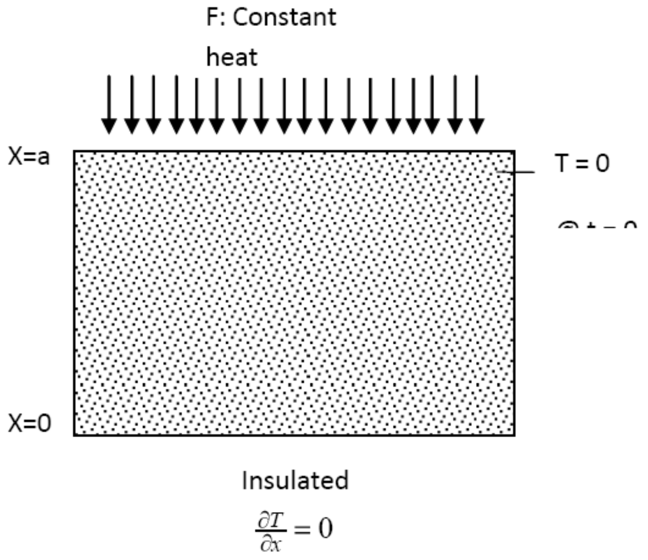

Fig.1. Diagram showing constant heat flux ‘F’ at the top surface of the specimen and the base is insulated.

2.1 1-D single-slab case

A 1-D theory of measurement of thermal conductivity was earlier described by Carslaw and Jaegar [1].They consider a slab that is initially at zero temperature, that is insulated at the surface x = 0 and has a constant heat flux introduced at the surface x = a, at time t = 0. They showed that temperature at a distance x within the rod and at time t (after the introduction constant heat flux at x = a) is given by

$$T(x,t) = \frac{F\alpha t}{aK} + \frac{Fa}{K}\left\{\frac{3x^2 - a^2}{6a^2} - \frac{2}{\pi^2}\sum_{n=1}^{\infty}\frac{(-1)^n}{n^2}e^{-\alpha n^2\pi^2 t/a^2}\cos\frac{n\pi x}{a}\right\} \qquad (2)$$

Where α is thermal diffusivity, k is thermal conductivity, and a is the thickness of the slab.

If measurement is made at the base of the slab (x = 0), the expression for temperature becomes

$$T(a,t) = F\alpha t/aK - Fa/6K + transient\ \ terms \qquad (3)$$

For times large relative to α Π /a, the transient terms are negligible, and the temperature versus time behaviour becomes linear, the intercept t on the T=0 axis is;

$$t_i = a^2/6\alpha \qquad (4)$$

This expression can be used to find the thermal diffusivity directly from a series of temperature versus time measurements. Further, the intercept T on the t=0 axis is equal to

-Fa/6K and the slope on m of the linear segment is equal to Fα/Ak. The three quantities t_i, T, and m can be combined to form the relation.

$$T_i = -m\, t_i \qquad (5)$$

Which can be used to test the internal consistency, or integrity, of any particular set of measurements made by this method, if the constant heat at the surface is known, the thermal conductivity can also be found from either T or m.

Equation (4) forms the basis for measuring thermal properties using this technique. In practice, temperature is plotted against time, the intercept t_i is read from the graph, and the thermal diffusivity is calculated using equation (4).The 1-D case is a good approximation of the experiment.

3.0 EXPERIMENTAL METHOD

Experimental method is based on the theory of Carslaw and Jaegar 1-D single-slab case and experiments are conducted on small circular specimens of hypereutectic Al-Si alloys with and without the addition of phosphorous, Titanium Boron and Titanium. A constant heat flux is applied on top surface of circular specimens and all other faces are thermally insulated as shown in the fig 2.Assuming a 1-D heat flow temperatures are measured at the center of a base of a circular cylindrical specimen.

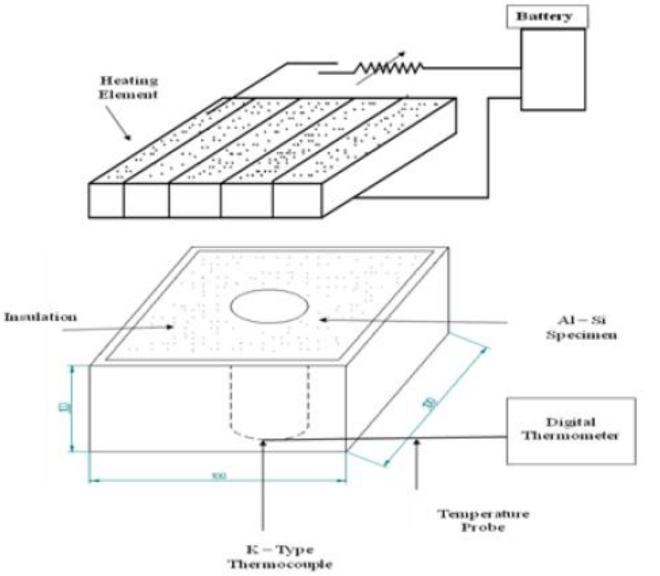

Fig.2. Schematic layout of experimental set up for the measurements of thermal diffusivity

3.1 Sample

A circular rod of approximately φ10mm x 50mm in vertical dimension is machined from the cast specimens of size φ12.5mm x 110mm and is lightly polished to achieve flat surfaces. all the other surfaces other than top are thermally insulated with low thermal conductivity material such as wooden block with glass wool insulation.

3.2 Heat Source

For achieving a constant heat flux a constant current is passed through a coiled wire element. With constant current flowing the wire will radiate with a near constant heat flux.The current can be adjusted so as to cause the wire to emit heat without glowing, if required. Wired coil is placed 10 mm above the top surface of the circular cylindrical specimen to have a thermal equivalent to an “oven effect” and approximately realizing a constant heat flux boundary condition. The other advantage of the configuration is that problems of thermal contact resistance are avoided at the top surface, and thus also the necessity to provide a finely polished surface.

3.3 Temperature Measurement

The temperature of the circular cylindrical specimen is measured by the help of a thermocouple with a needle probe of 1.5mm diameter centred at the base of the sample or specimen. The needle probe is connected to a digital thermometer. Needle probe has a 0.2 s time constant, which means that the true temperature is approximated to about 99.3 percent in one second. Maximum measurement rates are in the order of 1^oC in 10 seconds and the temperature measurement is fairly accurate and the error is typically 1 percent.

The major source of error is the base contact between the circular cylindrical sample of hypereutectic Al-Si specimen, the needle probe, and the insulation. A thin leaf of aluminium foil or copper foil is placed above the insulation layer to improve the thermal contact and to produce a uniform base temperature. In effect, the aluminium foil, which is a much better thermal conductor than the cylindrical sample or insulation, will distribute the base temperature around the temperature probe almost instantaneously.

3.4 Experimental Procedure

Temperature at the base of the circular cylindrical hypereutectic Al-Si specimen is measured for about 150 s by rapidly exposing top surface of the circular cylindrical specimen to the heat source. Time period measurement of 150s is generally sufficient to obtain a linear behaviour. The measured temperatures are reduced by subtracting the initial ambient temperature, effectively making the measurements relative to zero initial temperature. This reduced temperature is plotted against time, and the linear segment and intercept time t_i are then identified from graph. The thermal diffusivity is determined from the intercept time t_i by rearranging equation (4) thus;

$$\alpha = a^2/6t_i \qquad (6)$$

3.5 Specific heat

The specific heat is the amount of heat that has to be supplied or removed to change the temperature of unit mass by 1^0c.Specific heat of a substance is a function of temperature. For solids and liquids, value of specific heat varies with temperature and does not differ much for different processes. The specific heat of a material can be obtained by energy balance equation.

3.6 Procedure

100 ml of water is taken into the thermo flask and its initial temperature is recorded as (T_{w1}). The circular cylindrical specimen of hypereutectic Al-Si alloy is dipped in a separate water bath and water is heated. The heat is transferred to the specimen, which is the initial temperature of the specimen (T_{s1}). Now dip the specimen into the thermo flask and measure water temperature. Record the temperature of water, the final temperature of specimen is measured as T_{s2} and the final temperature of water is measured as T_{w2} when the temperature has largely stabilized (or is changing very slowly).

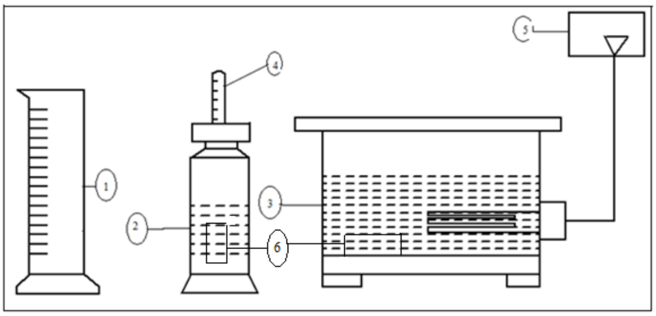

Fig.3. Schematic layout of experimental set up for the measurements of specific heat. 1. Measuring flask 2. Thermo flask 3. Heater coil arrangement 4. Thermo meter 5. Power supply 6. Specimen

Specific heat of hypereutectic Al-Si alloys is determined using energy balance equation (7)

$$m_w C_{pw} (T_{w2} - T_{w1}) = m_s C_{ps} (T_{s1} - T_{s2}) \qquad (7)$$

Where,

m_w-Mass of water
m_s-Mass of specimen
C_{pw}-Specific heat of water (4.178 J/kg K)
C_{ps}-Specific heat of specimen
T_{w1}-Initial temperature of water
T_{s1}-Initial temperature of specimen
T_{w2}-Final temperature of water
T_{s2}-Final temperature of specimen

3.7 Thermal Conductivity

"A thermal conductivity is the amount of heat transferred through a material of unit thickness with a temperature difference of 1^0c maintained across the bounding surface". Thermal conductivity is the property of the material which signifies about the transfer of heat by conduction. Thermal conductivity of the material mainly depends upon microstructure, chemical composition, density, state of the material and operating conditions such as pressure and temperature. Thermal conductivity of pure metals is higher compared to alloys with elemental additions. Alloying elements, impurities, porosity considerably decreases the thermal conductivity of pure metals. The thermal conductivity is essentially a coefficient of static heat transfer.

4.0 RESULTS AND DISCUSSIONS

4.1 Effect of microstructure on thermal properties

The thermal properties of the materials are greatly influenced by material microstructural features such as grain size, grain boundaries, pores and defects which reduce the thermal properties such as the thermal conductivity (k) thermal diffusivity (α) and Specific heat (Cp). Influence of the microstructural features is more significant at room and at below room temperatures [2]. Common microstructure of hypereutectic Al-Si alloys is mainly composed of primary aluminum dendrites in addition to primary silicon and eutectic. The high strength and wear resistance of these alloys are attributed to the presence of hard primary and eutectic silicon particles. So in hypereutectic Al-Si alloys size shape and distribution of primary silicon attributes for the mechanical, tribological and thermal properties. Minor elemental additions such as Phosphorous, Titanium Boron and Titanium are generally added to refine primary silicon and hence to improve mechanical and tribological properties. But with the addition of these grain refiners, the size and shape of the primary silicon is greatly affected as seen from Fig. 4, 5 and table 1.The thermal properties of hypereutectic Al-Si alloys decreases with refinement of primary silicon particles and it may be attributed to decrease in size of silicon particles and their even distribution. This may be the primary cause of reduction in thermal properties such as thermal diffusivity, specific heat and thermal conductivity.

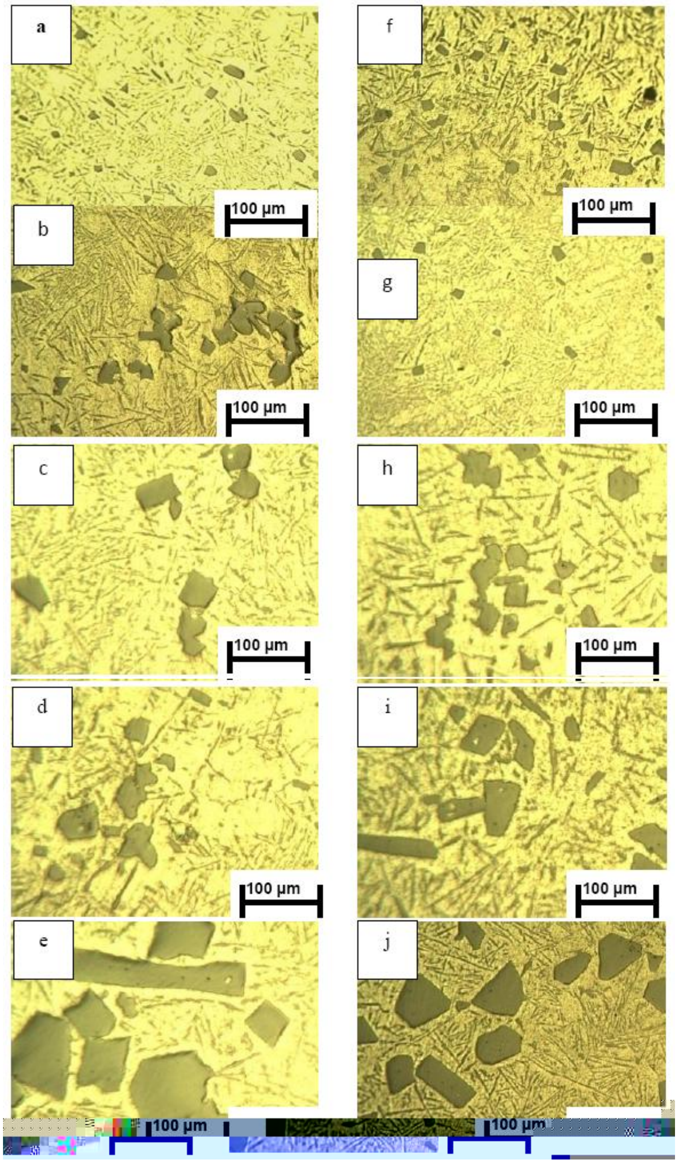

Fig.4. Optical micro photographs (200x) of hypereutectic Al-Si alloys before and after the addition of P. (a) Al-13 Si (b) Al-14 Si (c) Al-15 Si (d) Al-17 Si (e) Al-20 Si (f) Al-13 Si+0.02P g) Al-14 Si+ 0.02P (h) Al-15 Si+0.06 P (i) Al-17 Si+0.06 P (j) Al-20 Si+0.1 P

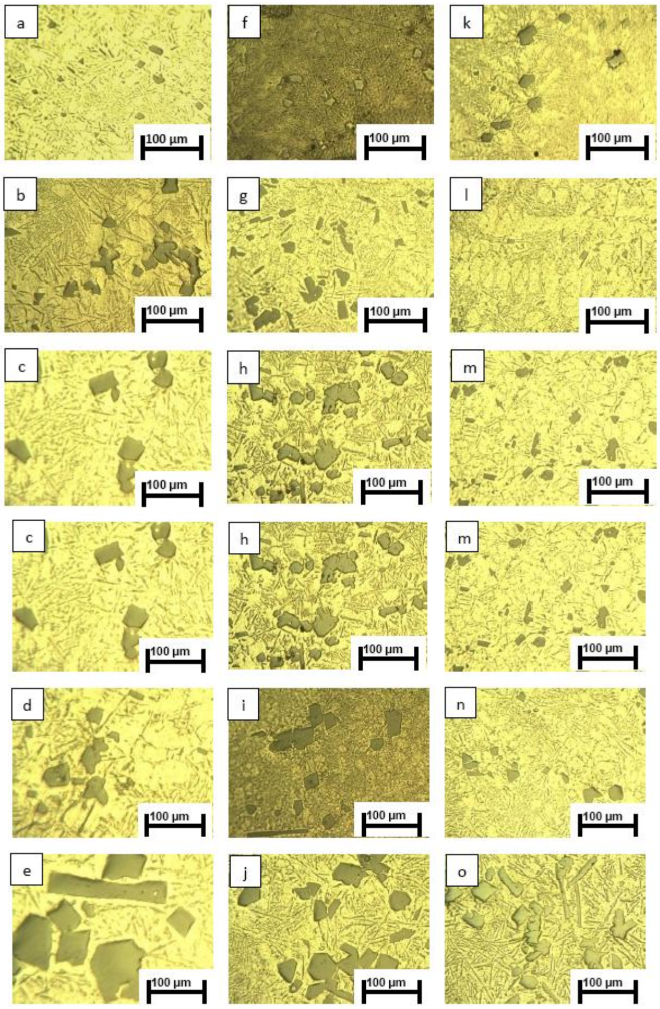

Fig. 5.optical micro photographs (200x) of hypereutectic Al-Si alloys before and after the addition of Al-5Ti-1B and Al-5Ti. (a),(b),(c),(d),(e) as cast hypereutectic Al-13,14,15,17 and 20 Si alloys (f),(g),(h),(i),(j) Al-13,14,15,17 and 20 si alloys with the addition of 0.15% TiB (k),(l),(m),(n),(o) Al-13,14,15,17 and 20 si alloys with the addition of 0.15% Ti

Table 1. Average primary silicon area in microns

Specimen	Average size of primary silicon in μm
Al-13Si	83
Al-13Si+0.02P	12
Al-13Si+0.15 % Al-5Ti-B	9.15
Al-13Si+0.15 % Al-5Ti	10.25
Al-14Si	92
Al-14Si+0.02P	18
Al-14Si+ 0.15 % Al-5Ti-B	12.25
Al-14Si+ 0.15 % +Al-5Ti	13.35
Al-15Si	100
Al-15Si+0.06P	23
Al-15Si+ 0.15 % Al-5Ti-B	18.52
Al-15Si+ 0.15 % +Al-5Ti	19.95
Al-17Si	123
Al-17Si+0.06P	25
Al-17Si+ 0.15 % Al-5Ti-B	20.50
Al-17Si+ 0.15 % +Al-5Ti	20.95

Al-20Si	132
Al-20Si+0.1P	40
Al-20Si+ 0.15 % Al-5Ti-B	21.35
Al-20Si+ 0.15 % +Al-5Ti	22.45

4.2 Effect on specific heat

Figure 6 shows the variation of specific heat of hypereutectic Al-Si alloys with and without the addition of Phosphorous, Titanium Boron and Titanium. It is observed that with increase in percentage of silicon and with elemental additions of Phosphorous, Titanium boron and titanium Specific heat decreases. It may be due to the refinement and even distribution of primary silicon particles after refinement.

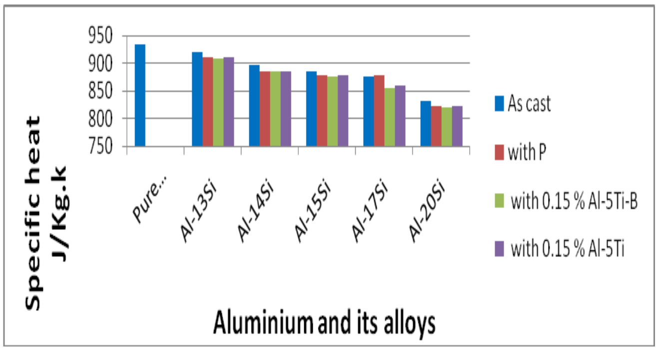

Fig. 6. Shows variation of specific heat Vs Percentage of silicon in aluminium with additions of grain refiners.

4.3 Effect on thermal diffusivity

Figure 7 shows the variation of thermal diffusivity of hypereutectic Al-Si alloys with and without the addition of Phosphorous, Titanium boron and Titanium. Thermal diffusivity is the measure of thermal inertia. In a substance with high thermal diffusivity, heat diffuses at a faster rate through the substance relative to its volumetric heat capacity or 'thermal bulk'. It is observed that with increase in percentage of silicon and with elemental additions of Phosphorous, Titanium-Boron and Titanium thermal diffusivity decreases and it is mainly due to distribution of silicon particles throughout the bulk of the material which resists the flow of heat;

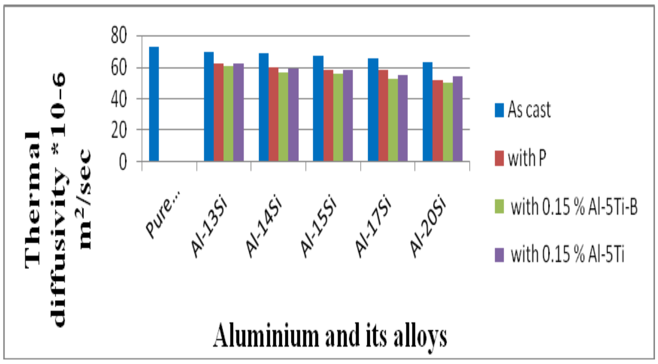

Fig. 7. Shows variation of Thermal diffusivity Vs Percentage of silicon in aluminium with additions of grain refiners.

4.4 Effect on thermal conductivity

Figure 8 shows the variation of thermal conductivity of hypereutectic Al-Si alloys with and without the addition of Phosphorous, Titanium boron and Titanium. Thermal conductivity is a measure of the transport of energy i.e. heat, through a body of mass as a result of temperature gradient. Thermal conductivity is thus a material-specific property used for characterizing steady heat transport. Thermal conductivity decreases with increase in silicon content and refinement; it is attributed to even distribution of primary silicon in the aluminium matrix.

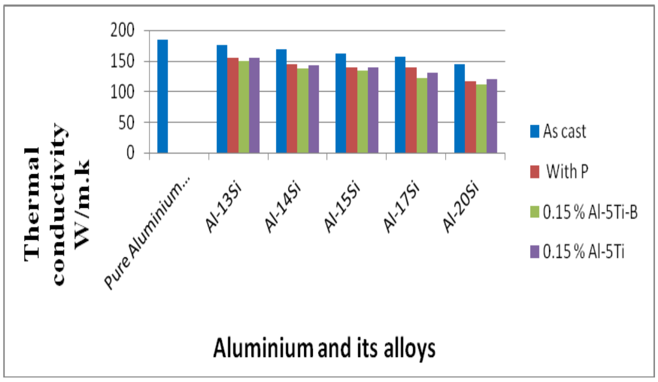

Fig. 8. Shows variation of thermal conductivity Vs Percentage of silicon in aluminium with additions of grain refiners.

5.0 Conclusions

Effect of elemental additions of Phosphorous, Titanium Boron and Titanium on thermal properties of hypereutectic Al-Si alloys is discussed in the present study.

The following are the conclusions that can be drawn from the results obtained.

1. It is observed in the present study that thermal properties like thermal diffusivity, thermal Conductivity and specific heat of pure metals decreases with alloying elements.
2. Refinement with the addition of Phosphorous, Titanium Boron and Titanium has detrimental effect on thermal properties of hypereutectic Al-Si alloys.
3. The transient method of determining the thermal properties is cost and time effective and can be applied to alloys, composites, monolithic metals and non metals.

References.

[1]. H.S. Carslaw ; J.C. Jaeger. Conduction of heat in solids; (2nd Edition). Clarendon Press, Oxford, 1959.

[2]. J. E. Parrott ; Audrey D. Stuckes. Thermal Conductivity of Solids. Pion Limited, London Pion; 1975.

[3] Zehraa N. Abdul-Ameer. Studying Some of Mechanical and Thermal Properties of Al-SiC composites. Journal of Al-Nahrain University. Vol.16 (2), July, 2013, pp.119-123

[4].. K.Y.Sastry ; L.Froyen ; J.Vleugelus ; E.H.Bentefour ;C.Glorieux. Effect of porosity on thermal conductivity of Al-Si-Fe-X alloy powder compacts. International Journal of Thermophysics.Vol. 25,No 5,September 2004.

[5]. A. G. Every ; Y. Tzou ; D. P. H. Hasselman ; R. Raj. The effect of Microstructure on the Thermal Conductivity of Particulate ZnS/Diamond Composites. Journal of Materials Research. January 17, 1991.

[6]. R. R. Babu ; N. K. Singha ; K. Naskar. Interrelationships of morphology, thermal and mechanical properties in uncrosslinked and dynamically cross linked PP/EOC and PP/EPDM blends. eXPRESS Polymer Letters. Vol.4, No.4 (2010) 197-209.

[7]. Robert A.Miller ; Maria A Kuczmarski. Method for Measuring Thermal Conductivity of Small Samples Having Very Low Thermal Conductivity. NASA/TM—2009-215460.

[8]. Mohamad Hassan Amin ; Mohsen Amin-Ebrahimabadi ; Mohamad Reza Rahimipour. The effect of Nano sized Carbon Black on Thermo mechanical Properties of Al_2O_3-SiC-SiO_2-C Composite. Journal of Nanomaterials.Vol.2009. Article ID 325674.

[9]. Eduardo J. Gonzalez ; Grady White ; Lanhua Wei. Effects of Microstructural Evolution on the Thermal Conductivity of γ-Al_2O_3 Prepared from Nanosize-Al_2O_3 Powder. Journal of Material research. Volume 15, Issue 03, 2000, pp 744-750.

[10]. Mike F.Middleton. A transient method of measuring the thermal properties of rocks. Geophysics, 1993, 58, pp 357-365.

[11]. S.A.Bowers ; J.Hanks. Specific heat capacity of soils and minerals as determined with a radiation calorimeter. Soil science, 1962, 94,392-396.

[12]. Olusola O. Fasunwonetal. Determination of thermal conductivity of rock samples using fabricated equipement. Thermal science, 2008, 12,119-128.

[13]. Tye, R. P ; Kubičár, L ; Lockmuller, N. The development of a standard for contact transient methods of Thermophysical properties. Int. J. Thermophysics., 2005, **26(**6), pp 1917-1938.

[14]. James Adeyemo Adegoke ; Babatunde Ogunsile ; Adekunle; Oluwatoyin Adetoro.Variation of Thermo physical properties of clay with adsorbtion optimization. The pacific Journal of science and technology. 2010, 11,639-648.

[15]. G. L. Oyekan ; O. M. Kamiyo. A study on the engineering properties of sandcrete blocks produced with rice husk ash blended cement. Journal of Engineering and Technology Research.Vol. 3(3), pp. 88-98, March 2011.

[16]. Ramakrishnan D ; Bharati R ; Nithya M; Kusuma K N ; Singh KD. Measurement of thermal properties of select intact and weathered granulates and their relationship to rock properties.Geophysics, 77(3), D63-D73.