A Literature Review on Thermal Properties Measurement of Additively Manufactured 17-4ph Stainless Steel Alloy

Anuth V L [1], Mrs. Parimala Murugaveni .S[2]
[1, 2] Dept of Mechanical Engineering
[2]Associate Professor, Dept of Mechanical Engineering
[1, 2] Government College of Technology, Coimbatore -641 013,Tamil Nadu,India.

Abstract- *Additive Manufacturing plays a major role in producing many industrial alloys by layer by layer manner using Laser Powder Bed Fusion. It produces high value components that are difficult to produce using conventional methods. In this project 17Cr-4Ni (17-4PH stainless steel) alloy which is a family of martensitic, precipitation hardening stainless steel powders, was taken for investigation. The 17Cr-4Ni alloy is based on Ni & Cr is widely suggested for the aerospace and medical applications, as it is corrosion resistance and acid resistance. In this work, a literature review on 17-4PH alloy is done to identify the research gap in thermophysical properties of this alloy, as it is fabricated using additive manufacturing method. The topics concentrated in the review are Additive manufacturing, Thermophysical properties of alloys, Different equipments and methods for measuring thermophysical properties*

Keywords- Thermal Properties,-Measurements-Equipments..

I. INTRODUCTION

Additive Manufacturing (AM) techniques are used in various industries to create physical prototypes as well as end-use parts. AM has the ability to allow custom build or personalized production of materials with almost accurate precision and resolution. This method helps produce using metallic or non-metallic products directly by a designing computer software called Computer Aided Design (CAD). The most important feature of AM is the liberty it provides to the product on CAD and hence the liberty in production of the parts with almost any geometry. AM permits the fabrication of advanced part designs which provide additional space, multifunctional parts, and parts that are difficult to machine. AM permits to vary materials in a component according to its suitability, and to control the construction process starting from a digital mode. Features like these and the increase in high precision and time saving fabrication process has led to the rapid growth of this 3D Printing technology. These multiple advantages can be utilized if the building components and AM processes are fabricated competently in the designing and drafting phase. The quality of AM to fabricate complex designs which high precision makes it suitable for the aerospace industry.

Additive manufacturing, also known as 3D Printing or rapid prototyping worldwide, is a way to join materials to form 3D models from 3D data. It is a computer controlled process which produces the product by constructing it layer by layer which is opposite when it comes to subtractive manufacturing, such as machining. Additive Manufacturing, as inferred by its name, suggests that it adds material to produce an object. Each layer sticks to the previous layer of partially melted material. Parts are digitally modified by computer-aided design (CAD) software that is used to create .stl files that "chop" the part into ultra-thin layers. The data from CAD guides the path of a nozzle as it accurately deposits material on the previous layer. As materials are cured, they fuse together to form a three-dimensional object. It can be used to produce anything, and its application are limitless, whether the product is made of plastic, concrete, or metal, it could someday with more advances also help produce human tissue onto making a human organ.

II. PROJECT OBJECTIVES

Additive Manufacturing produces different forms of alloy. As new alloys are developed there is always a need to determine its thermal properties. So in this project 17Cr-4Ni (17-4PH STAINLESS STEEL) ALLOY which is a family of martensitic, precipitation-hardening stainless steel powders, was taken for investigation of material property,Thermal properties such as Thermal Conductivity, Specific Heat, Thermal Diffusivity and its measuring equipments were determined.

III. PROJECT SPECIFICATIONS

Additive Manufacturing plays a major role in producing many industrial alloys in layer by layer using the technique called Laser Powder Bed Fusion. It produces complex components that are difficult to produce using conventional methods. In this project 17Cr-4Ni (17-4PH stainless steel) alloy which is a family of martensitic, precipitation hardening stainless steel powder, was taken for investigation of properties and analysis of high temperature application.

IV. LITRATURE SURVEY

The main aim of this chapter is to provide the background information about the proposed study from an extensive literature survey view point. From this literature review, a planning and an understanding of the present work have been achieved. Additive manufacturing, Thermophysical properties of alloys, Different equipments and methods for measuring thermophysical properties have been surveyed through this chapter. A lot of investigations have been carried out to investigate the Thermophysical Properties of alloys.

ADDITIVE MANUFACTURING

Wei Gao et al., because of its capacity to build complex shapes with configurable material properties, additive manufacturing (AM) technology has piqued academic and business attention. By democratising design and manufacturing, AM has also aided the growth of the maker movement. There is a lack of a comprehensive set of design concepts, production rules, and standardisation of best practises due to the rapid expansion of a wide array of technologies related with AM.

Mariano Jimenez et al., because the scale of the production run and the geometrical complexity of the component limit the use of traditional manufacturing methods, we are occasionally obliged to adopt processes and tools that raise the final cost of the element being produced. Due to the fact that additive manufacturing techniques adapt to the geometrical complexity and customised design of the part to be manufactured, the following benefits may be achieved depending on the field of application: lighter weight products, multimaterial products, ergonomic products, efficient short production runs, fewer assembly errors and, thus, lower associated costs, lower tool investment costs, a combination of different additive manufacturing techniques.

G. M. Shashi et al., By utilising modern technology, Additive Manufacturing (AM) has given a new dimension to the manufacturing process. The use of additive manufacturing technology in several industries has risen dramatically in recent years. It goes over the various AM approaches as well as their advantages. Before analysing the current situation in Additive Manufacturing, it will explore many empirical applications of AM. Furthermore, an attempt is made to identify future AM difficulties and opportunities.

Santosh Kumar Parupelli et al., 3D printing, commonly known as additive manufacturing (AM), is a process for creating three-dimensional (3-D) solid items. 3D printing may be used to manufacture customised 3D items with complex geometry and integrated functional designs. A complete study of the AM process is given, with an emphasis on recent developments made by various researchers and industries. A summary of the capabilities, advantages, and limits of each 3D printing method is offered. It examines key advances in 3D printing applications in a variety of sectors, including electronics, medicine, aerospace, automobiles, building, fashion, and food.

EQUIPMENTS AND METHODS FOR MEASURING THERMOPHYSICAL PROPERTIES OF ALLOYS

B. M. Angadi et al., This paper aims of the paper is to describe the rapid transient method for the determination of thermal properties like thermal diffusivity and thermal conductivity of hypereutectic Al–Si alloys such as Al-13, 14, 15, 17 and 20 Si alloys. The present transient method is based on the application of constant heat flux to the top surface of cylindrical Al-Si specimen that is insulated on all other surfaces. It is observed from the present study that, increase in the percentage of silicon content results in reduction in the values of thermal properties of hypereutectic Al-Si alloys.
Llavona et al., It includes a description and discussion of the experimental methods for determining the thermal conductivity of solids, liquids, and gases over a broad temperature range, as well as applications to conductor and insulating materials, metals, refractory products, ceramics, powdered and packed solids, and other materials. A list of references is also included, which includes I.S.O., D.I.N., and A.S.T.M. Standard Tests, as well as experimental methods, studied methodologies, theoretical approach, error analysis, and recommended enhancements of current techniques that we thought were pertinent.

Barbara Nasiłowska et al., This paper presents the results of the structural investigations and thermophysical properties of 904L steel parent material. Experimental studies on the structure of 904L steel proved a pure austenitic structure. Both the experimental research and analysis of the thermophysical properties of 904L steel were complemented with the results of the thermal conductivity calculations for the tested material. The paper presents a brief description of the measurements, the procedures for evaluating the data, and a set of the obtained results.

Ramiz Delpak et al.,Their goal of this study was to determine the relationship between varying percentages of damage and concrete's thermal conductivity. The effect of various damages on the internal conductivity of concrete was investigated. Thermal conductivity was measured using the method with insulation (ordinary method), which is 24 based on measuring the temperature difference between two surfaces of a specimen when one of the surfaces is heated. For each measurement of thennal conductivity, three specimens were used for each % of damage. One conclusion that can be drawn from this study is that varied percentages of damage have an impact on the internal conductivity of concrete.

LASER FLASH METHOD

Libor Vozar et al., This paper examines data-reduction method so algorithms for calculating thermal diffusivity from experimental data. It also includes references to many original papers that detail the experimental setup. The flash method is used to evaluate advanced materials such as semi-transparent media, materials with considerable temperature dependency of their thermophysical properties, anisotropic materials, layered structures, thin films, and composites. It's a quick remark on several experimental procedures that stem from the flash method.

lmo Kukkonen et al., The purpose of this study is to compile data from the literature on in-situ thermal property measurements used in geothermal, waste disposal, and other projects. The findings are also being utilised to develop a preliminary assessment of a measurement system that could be employed in Finland's spent nuclear fuel programme. We offer a forward and inverse modelling analysis of a measuring system for single holes, as well as a number of recommendations for realistic probe development.

G. Penco et al., They described using the Laser Flash approach to assess the thermal conductivity of deposited copper using the Pure Coat technology in the normal direction. The thermal transient investigation was made possible by the employment of Au-Fe/Cromel P thermocouples as temperature sensors, which was driven by the necessity to convert traditional technology from ambient temperature to cryogenic conditions. To reduce noise and heat dissipation effects, a lot of effort has gone into developing data analysis processes. The results confirm the interest in the copper spraying stiffening for the SC cavities, and the measurements have confirmed the apparatus's reliability.

A Sh Agazhanov et al., The thermal diffusivity (a), linear thermal expansion coefficient (α), isobaric heat capacity (Cp) and phase transition enthalpy (ΔH) of Inconel 718 super alloy were determined by laser flash method, dilatometry method and differential scanning calorimetry in the temperature range of 298–1375…1473 K. The thermal conductivity (λ) has been calculated from the measurement results. The estimated errors of the obtained data were 2–5%, 3–5%, 2– 3% and (1.5–2)×10–7 K–1 for a, λ, Cp and α, respectively. The approximation equations and a table of reference values for the studied properties have been obtained.

A. Gobel et al., The rear-side temperature rise is compared to specific-heatcapacity data collected by other methods in a nearby temperature range to establish calibration. The proportional factor obtained in this way is then used to calculate the specific heat capacity from laser-flash observations at temperatures where no specificheat-capacity data is available. Measurements on aluminium oxide, a material with a known specific heat capacity, demonstrate the method's trustworthiness. Furthermore, the thermal conductivity and specific heat capacity of borosilicate crown glass (BK7) were measured experimentally.

S. Alterovitz, et al., A heat pulse is applied to one end of a finite one-dimensional sample, which is clamped to a heat sink on the other end. The absolute values of the thermal diffusivity, heat capacity, and thermal conductivity are determined by analysing the following temperature rise in the centre of the sample using the moments approach. An on-line computer analysis was performed because the procedure is based on pulse shape analysis. The experimental setup was utilised to see if sintered AI 20 J (ceramic) could be employed as a suitable substrate for thin film heat capacity investigations at low temperatures.

Dilek Kumlutas et al., Numerical and experimental studies of the heat conductivity of particle-filled polymer composites are conducted. Using the results of the thermal analysis, the finite-element programme ANSYS is used to compute the thermal conductivity of the composite in the numerical research. The microstructure of composite materials is simulated using three-dimensional models for varied filler concentrations and thermal conductivity ratios of filler to matrix material. Cubes in a cube lattice array and spheres in a cube lattice array are the models used to represent particle loaded composite materials. The thermal conductivity of composites made up of a high-density 28 polyethylene (HDPE) matrix loaded with tin particles up to 16 percent by volume is measured using a modified hot wire method.

Mark D. Katz et al., It is concerned with the evaluation of laser-pulse method for determining constructional materials thermal characteristics systematic errors under high temperature settings. The impact of heat exchange with the surrounding air on 27 systematic mistakes is examined in depth in this article. It is demonstrated that the laser pulse method may be utilised to calculate the thermal diffusivity and thermal capacity of high thermal diffusivity metals and alloys at temperatures below 1173 K

DIFFERENTIAL SCANNING CALORIMETRY

F. Cernuschi et al., shows how to measure thermal diffusivity using a variety of methods. Any technique, both in the experimental layout and in the processing algorithms, is given a brief overview. The results of samples cut from the same block of AISI 304 stainless steel are presented. Any measurement's level of uncertainty is also indicated. Thermal conductivity and/or thermal diffusivity are becoming increasingly important in many industrial applications. In reality, when heat transfer mechanisms are involved, these are the most significant characteristics.

Hoda Malekpour et al., They describe a Raman spectroscopy-based method for measuring thin film thermal conductivity and analyse notable results obtained with this technique in graphene and other two-dimensional materials. The opt thermal Raman approach was crucial in the discovery of graphene's unique heat conduction capabilities. Raman spectroscopy is used to determine the sample's local temperature, and the excitation laser is used as a heat source in this procedure. Raman spectroscopy's effectiveness in studying the thermal conductivity of suspended graphene and graphene-based thin films prompted its application to other material systems and films.

Dongliang Zhao et al., This paper examines a few of the most widely used measurement techniques. In general, determining thermal conductivity and interfacial thermal conductance with less than 5% error is a difficult process. Understanding of the fundamentals and procedures of the testing technique, for example, some techniques are limited to samples with specific geometries and some are limited to a specific range 29 of thermophysical properties; acknowledge of the sample whose thermophysical properties are to be determined, including the sample geometry and size, and the material preparation method; acknowledge of the sample whose thermophysical properties are to be determined, including the sample geometry and size, and the material preparation method; acknowledge of the sample whose thermophysical properties are to be measured.

R Thaib et al., The process of shifting the two phases of PCM, which is difficult to monitor, is a flaw in the calorimetry method. At this time, the T-history approach, which requires minimal equipment, was frequently employed. It investigates how we can measure the thermophysical properties of phase change materials that will be employed as heat storage materials in solar water heating systems using the T-History approach. Paraffin, beeswax, bovine fat, and a blend of the materials in a certain ratio are the materials. The results of the test show that employing the T-History method produces good results, with a difference of 7% between the DSC measurement results and the THistory method.

A. Arriagada et al., They proposes an enhanced thermal transient approach that allows simultaneous measurement of thermal conductivity and specific heat of nanoscale objects with one-dimensional heat flow. The temporal response of a sample to finite duration heat pulse inputs is analysed and exploited to derive thermal properties for both short (1 ns) and long (5 ls) pulses. Choosing an optimal pulse width resulted in excellent agreement between the retrieved physical parameters and computational calculations.

Syamsul Hadi et al., This paper describes the methods for designing, building, and certifying thermal conductivity apparatus that use steady-state heat-transfer techniques to test a material at high temperatures. The ASTM D5470 standard employed meter-bars with similar cross-sectional area to infer surface temperature and quantify heat transfer over a sample, but this design improves on that. In the equipment, there were two meter-bars, each with three thermocouples. This apparatus uses a 1,000-watt heater to heat water and cool it to a steady temperature. The pressure was 3.4 MPa at 113.09 mm2 meter-bar and thermal grease was used to reduce interfacial thermal 30 contact resistance. To determine the performance, the validating process compared the results to the thermal conductivity acquired by LINSEIS' THB 500.

ERRORS IN METHODS

G. V. Kuznetsov et al., The inaccuracies in determining the thermal characteristics of materials using the laser flash method, which are dependent on the sample thickness and heating pulse duration, are estimated. The estimations are derived by comparing the true values of these features with the results of the numerical solution of the one-dimensional heat-conduction problem in samples of materials when a short pulse acts on their surface under conditions comparable to the experiment.

Mark D. Katz et al., Under conditions consistent with the implementation of the laser pulse method, errors in determining the thermophysical characteristics of typical organic liquids, specified by conductive-radiative heat transfer of ultrathin heated up to high temperature sample layer, were investigated when exposed to the surface of a collimated laser pulse of finite duration. The effect of the radiation absorption process on the error was discovered.

Aparna Zagabathuni et al., When evaluated using the transient hot-wire method, a suspension of particles smaller than 100 nm, commonly referred to as Nano fluid, generally exhibits a significant increase in thermal conductivity. When the conductivity of the same Nano fluid is measured using the laser flash method, however, the reported enhancement is about one order of magnitude smaller. For the first time, this discrepancy has been quantified using the suggested collision-mediated heat transfer model for Nano fluids.

V. RESULTS

From the above literature survey the following pros and cons of different additive manufacturing process are illustrated in the below table.

Additive Manufacturing Process	Advantages	Disadvantages
VAT Photopolymerisation	1. High level of accuracy and good finish 2. Relatively quick process 3. Typically large build areas: object 1000: 1000 x 800 x 500 and max model weight of 200 kg	1. Relatively expensive 2. Lengthy post processing time and removal from resin 3. Limited material use of photo-resins 4. Often requires support structures and post curing for parts to be strong enough for structural use.
Binder Jetting	1. Parts can be made with a range of different colors 2. Uses a range of materials: metal, polymers and ceramics 3. The process is generally faster than others 4. The two-material method allows for a large number of different binder-powder combinations and various mechanical properties	1. Not always suitable for structural parts, due to the use of binder material 2. Additional post processing can add significant time to the overall process
Powder Bed Fusion	1. Relatively inexpensive 2. Suitable for visual models and prototypes 3. (SHS) Ability to integrate technology into small scale, office sized machine 4. Powder acts as an integrated support structure 5. Large range of material options	1. Relatively slow speed (SHS) 2. Lack of structural properties in materials 3. Size limitations 4. High power usage 5.Finish is dependent on powder grain size
Directed Energy Deposition	1. Ability to control the grain structure to a high degree, which lends the process to repair work of high quality, functional parts 2. A balance is needed between surface quality and speed, although with repair applications, speed can often be sacrificed for a high accuracy and a pre-determined microstructure	1. Finishes can vary depending on paper or plastic material but may require post processing to achieve desired effect 2. Fusion processes require more research to further advance the process into a more mainstream positioning
Fused Deposition Modeling (FDM)	1. Complex parts can be produced with good accuracy and with low cost when compared to conventional manufacturing process. 2. No need for special tooling's. 3. As simple as printing of copy from normal inkjet printer.	1. DM is a costlier process. 2. The size of the output product is limited to a very small size. 3. Raw material limitations. (No metal-based filaments can be used due to requirement of high temperatures).

From the above literature survey for the manufacturing of aerospace and medical application the powder bed fusion method can be used because of its easy manufacturing process, less material removal rate, high accuracy in production and to increase the strength and corrosion properties of the products. It is very less expensive when compared to other methods. It increases the grain size of the particle.

RESULTS OF LITERATURE REVIEW ON EQUIPMENTS & METHODS FOR MEASURING THERMOPHYSICAL PROPERTIES OF ALLOYS

From the literature survey the following conclusions on Advantages and Disadvantages of Equipments Measuring Thermal Properties were illustrated in below table

Apparatus	Thermal Properties	Advantages	Disadvantages
Laser Flash Apparatus	1.Thermal diffusivity 2.specific heat capacity	1. Measures TC from 300K to 1370K 2. Measures 3 samples in about 24 hours	1. Non-uniform Heating 2. Heat Loss 3. Pulse Duration 4. Accuracy ± 10%
Differential Scanning Calorimetry	1.Specific heat capacity	1.Versatility 2.Rapidity 3. No need calibration over the entire temperature.	1.Not to be used in overlapping reactions 2.Accuracy 10-15%

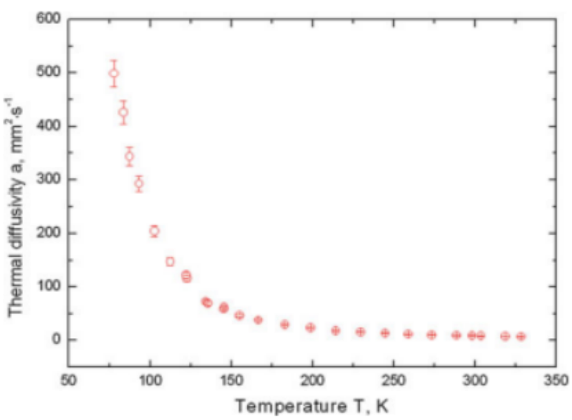
From the above literature survey due to high accuracy, high temperature range, different range of sample holding device, Number of samples measured per hour & Orientation of measuring sample Laser Flash Apparatus is determined as a best method for measuring Thermal Diffusivity and Specific Heat Capacity and Thermal Conductivity since it is a product of Thermal Diffusivity, Specific Heat Capacity & Density.

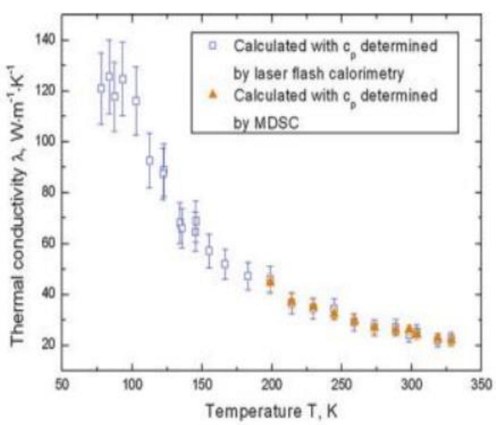
VI. DISCUSSION

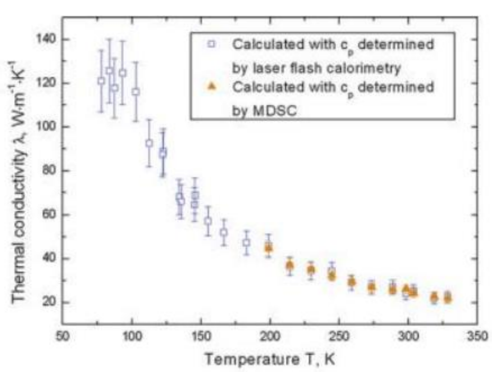
From below figure it is illustrated that when the heating temperature increases the Thermal Diffusivity decreases. As from the figure when the temperature is 100k the thermal diffusivity is 600mm2s -1 , then it decreases below 100mm2s -1 at 350k.Thus there is a pulse heating loss occurring.

From the below figure the Specific Heat and Thermal Conductivity increases and decreases with respective to

Temperature, T. As from figure 3.3 when the Temperature is 100 k the Specific Heat Capacity is less than 0.2J.g-1 .K-1 and it increases to 0.9 J.g-1.K-1 when the Temperature is 350k.From figure 3.4 when Temperature is 100k the Thermal Conductivity is140Wm-1K-1 and it decreases to 20 Wm-1K-1 when the Temperature is 350k. From figure the accuracy in the data of different methods or equipments such as Laser Flash Apparatus, Differential Scanning Calorimetry is in the range of ±10%.







VII. CONCLUSIONS

The literature survey is done in topic of Additive manufacturing, Thermophysical properties of alloys, Different equipments and methods for measuring thermophysical properties. And suitable manufacturing method from the above discussions is determined as Laser Powder Bed method because of its easy manufacturing process, less material removal rate, high accuracy in production and to increase the strength and corrosion properties of the products. And the thermal properties to be measure are Specific Heat Capacity, Thermal Diffusivity & Thermal Conductivity and the Equipment to measure the above thermal properties is determined from the above literature survey as Laser Pulse Method because of high accuracy, high temperature range, different range of sample holding device, Number of samples measured per hour & Orientation of measuring sample. Also the accuracy in the data of different equipments such as Laser Flash Apparatus, Differential Scanning Calorimetry is in the range of ±10%.

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