وزارة التعليم العالي والبحث العلمي
جامعة ديالى
كلية الهندسة

توصيف المواد المركبة وتحليل الاجهادات في حوض زيت المحركات

رسالة
مقدمة الى كلية الهندسة جامعة ديالى
وهي جزء من متطلبات نيل درجة ماجستر علوم
في الهندسة الميكانيكية

من قبل

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Ministry of Higher Education
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Material Characterization of Composites and Stress Analysis of Engine Oil Pans

A Thesis Submitted to the Council of the College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

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September, 2017 ***IRAQ*** ***Dhu al-Hijjah, 1438***

Chapter One

Introduction & Literature Review

1-1 Introduction

It is a knowledgment truism that the development in a technology is depending on advances in the materials field. Where, that no benefit in design the most advanced automotive or aircraft if appropriate materials to bear the service loads and circumstances are not available. Whatever the field is, the materials are the first condition of the advance development[1]. Composite materials are the combination of two or more materials that have one or more various properties. Combining materials together gives new properties to composite. The composite is used for improving the properties of the mechanical, physical, thermal, tribological, electrical, and environmental application [2]. Usually, the achievement of a required balance of properties of the composite materials is optimized for an appointed group of applications. Difficult to agree upon a single and simple definition, because there is a range of materials which would be considered as composite materials and the wide range of uses for which may be designed the composite materials. However, the practical common definition may be limited to confirm materials that have a matrix to link the contents together and provide strength and stiffness constituent of reinforcement. The balance of structural properties in composite material resulting is supreme compared with material alone [3]. In this regard, composite materials represent nothing but a giant step in the ever-constant attempt for the optimization of the materials. In the strict sense of the word, the idea of composite materials is not a new. The most common examples where the use of composite materials is the nature[4].

In the 1930s, modern composites were used when the glass fibers were reinforced with resins. By these glass composites, the boats and aircraft were built, commonly called fiberglass. Since the 1970s, a development of new composite systems with matrices made of metals and ceramics and new fibers such as carbon, aramids, and boron led to increasing the composite material applications[5]. A lightweight structural composite is an example of a composite material that is acquired by putting continuous carbon fibers in one or more orientations in a matrix of the polymer. This fiber gives higher strength and stiffness, while the polymer works as a matrix. The attractive properties of polymer- matrix reinforced with carbon fiber composites are low density (compared with aluminum), high strength, high stiffness , good creep resistance, good wear resistance and good chemical resistance (controlled by the polymer matrix)[6].

The purpose of the lightweight structure is to expand or even maintain the function of the product while decreasing the overall product weight. Present approaches to mass reduction include the use of materials which have low dense, eg, composite materials, metal foams or a decrease in the volume of material by reducing thicknesses of the wall in structural components. In the manufacturing process of lightweight composite structures, the technologies indicate the ability of uses the fiber-reinforced thermoplastic materials. The main motivators for the lightweight materials applications are weight savings and possible cost savings. Significant weight reductions with improved performance[7]. The need for high performance and the capacity of designing material properties to meet particular requirements has made the composite polymeric materials is the first choice for many applications in automotives and aerospace. These materials can be designed to give more strength in addition to relatively low weight and resistance to corrosion to most chemicals and provide long-term durability under most severe conditions environmentally. The key advantages of polymer materials compared with other conventional metallic materials was their properties of specific strength with saving (20-40%) of weight, good fracture resistance, ability to provide the stability dimensional and lower thermal expansion properties. There is also a need to process optimization for specific structural and semi-structural applications. The use of lightweight materials also aligns with most recent energy conservation regulations and policies. So, the basic objectives for development must be the use of hybrid composite materials, the highly automated evaluation of the rapid manufacturing processes including the application of smart preforms, and the possibility of used glass or carbon fiber reinforced in the matrix of thermoplastic or thermoset polymer materials for structural composites [8].

In automotives, the polymeric materials applications are increase constantly, and this direction is expected to continue. The main factors in selecting the polymeric materials with regard to other materials applied in automotives are today's appearance automotives, their functionality as well as reduced fuel consumption. In spite of the main purpose of choosing polymeric materials is reducing the mass of the parts, the future growth in their usage will produce new applications in automotives which is related to safety, comfort, and the possibility of integration the parts. The polymeric materials application allows more freedom in design and in many cases. Only these materials can allow safe economic or geometrical solution for the design of parts. The polymeric materials in automotive parts are divided into three classes: internal and external parts and bodywork engine parts[9]. In spite of the potential advantage of lower weight and durability resulting from corrosion resistance. Advanced composite materials are not known as a material choice in the near term for the applications of automotive. There is a need to make advanced composite materials attractive for widespread commercial use in automotives and trucks. The high cost of the raw and manufactured materials is the main obstacle when compared to existing options.

However, the automotive’s segment of composite materials represents about 24% of the thermoset and 50% of the thermoplastic from the composite market in the world. Polymer reinforced by fiberglass or carbon fiber is a promising material for reducing the weight due to the relatively low cost of the fiber. Pressure for lower emissions levels and reductions energy consumption makes advanced composite materials an appropriate option for the automotive sector. The probable future opportunities in the sector of automotive are as follows [10]:

- Epoxy/Fiberglass springs for heavy trailers and trucks
- Suspension arms, rocker arm covers, shrouds of wheels and engine
- Engine oil tanks
- Body components and assembly units for electric automotive
- Guides of the valve
- Brakes of automotive race
- The clutch plates.

In the applications of automotive, the internal combustion engines have on the bottom side an important part that sealed by a large metal pan called oil pan. It holds the oil engine and acts as a reservoir of oil. During engine operation, oil pump draws the oil from the pan and spread it through the engine, it allows the oil to return to the oil pan after it has passed through the engine. It’s a place to collect the oil if the engine is stopped and it is also a place for the collection of the impurities of oil and it allows for removal of the old oil. It also cools the oil by passing the air over the pan surface. Oil pans are manufactured from an aluminum alloy and bolted to the bottom of the crankcase and it is considerd as detachable mechanisms. To maximize its function, it is designed into the deeper section and it is placed at crankcase bottom to serve as a reservoir of oil. To protect the engine from the damage, some oil pans contain one or more magnets designed to capture the small metal pieces before they can plug the oil filter[11]. Engine components are shown in **figure (1-1)** and the oil pan is shown in **figure (1-2)**.

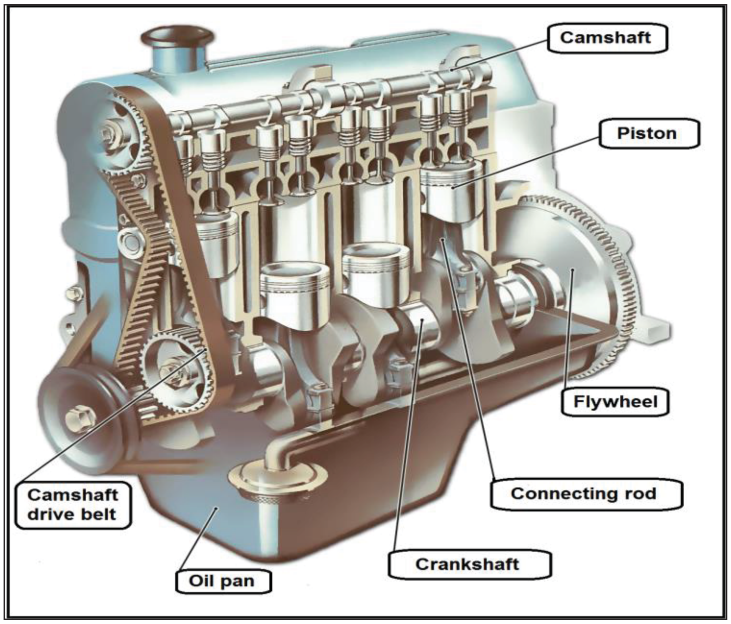

Fig. (1-1): Oil pan as a part of engine components.

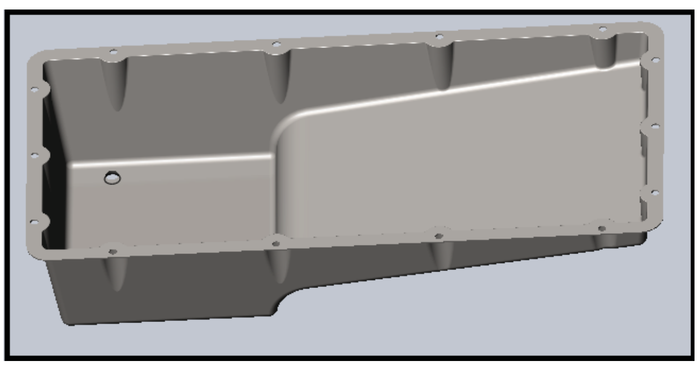

Fig. (1-2): Oil pan part.

To have the best engine performance, a particular operating temperature should be controlled. One cannot maintain this temperature only by using engine oil that works as a coolant. Therefore, it needs a component to store the oil and reuses it continuously. The essential purpose of oil pan in the engine, in addition storage part, the oil pan will collect some sediment by engine oil and transients it through the engine. Also, the oil pan acts as a bottom engine cover[12].

1-2 Literature Review

In (1982), E. P. Chang et al., Elucidated the mechanical and thermal properties of Phenolic - Formaldehyde resin reinforced by carbon fiber and fiberglass, and compared with the epoxy reinforced by the same fibers. The results showed that the phenolic composite has high thermal stability and mechanical properties close to epoxy composites. The sizing process of carbon fiber does not affect the mechanical properties and the conclusion is that the interlaminar shear strength increases with the increase of the sequence geometry of fibers[13].

In (2002), H. Kareem, studied the mechanical properties of epoxy reinforced by nickel particles with various volume fraction and size of particles. The results showed that the values of modulus of elasticity and yield strength increase with the increase of the volume fraction of particles, and the increase of particle size up to (32 μm) causes an improvement in the composite properties[14].

In (2003), Patel et al., studied some mechanical properties (tensile strength, impact strength and flexural strength) of (Epoxy – phenolic novolac) by using assistance agents to different phenol like (Cardanol , Phenol , P-cresol , P-tertbutyl-Phenol) with formaldehyde. These resins used the glass as a filler to prepare the composites. The results proved that the blend of Epoxy/novolac causes an increase in the mechanical properties[15].

In (2004), Zhang et al., studied the wear resistance of Epoxy resin reinforced by (Nano TiO_2) and carbon fibers. The test was carried out at different speeds. The results of this study showed that Epoxy/TiO_2 have more wear resistance than Epoxy/carbon fibers[16].

In (2006), Suresha et al., studied the wear resistance of Epoxy resin reinforced by fiberglass type of (E-glass) and different fillers (graphite and SiC). The test was done in dry condition. The results proved that the addition of filler (SiC) caused a decrease in wear rate of Epoxy resin reinforced by fiberglass[17].

In (2007), El-Akabi F. S., elucidated the effect of mechanical properties (tensile strength, impact strength and flexural strength) of Epoxy filled by copper powder with particle size ($d \leq 32$, $45 \leq d \leq 52$ μm) and weight fraction of (10%, 20% and 30%) and the graphite powder with particle size ($40 \leq d \leq 52$ μm) and weight fraction of (5%, 10% and 15%). The results revealed that the increase of weight fraction of copper powder for different particle sizes caused an increase in tensile strength and impact strength but at the same time will decrease the flexural strength, and the decreasing in particle size of copper powder improved the mechanical properties. Also, the increase in weight fraction of graphite powder leads to decrease in tensile strength, flexural strength and impact strength[18].

In (2008), Almusawi and Albdiry, studied the mechanical properties of phenol- formaldehyde resin reinforced by Kevlar fibers in two directions (0-90) with different weight ratios (20%-60%) and studied the impact resistance, tensile strength, and hardness, and compared it with mechanical properties of phenol-formaldehyde before reinforcement. The results showed an increase in tensile strength, impact strength and hardness[19].

In 2008, Huda J. Jaafer, elucidated the effect of wear resistance before and after immersion in a chemical solution (NaOH, HCl) of two type of polymer blend. The blends are binary (Epoxy/unsaturated polestar, Epoxy/novolac) and ternary (Epoxy/unsaturated polestar/novolac) with different blend ratio. The result showed that the wear rate decreased in binary blend compared with the ternary blend, and the increase in immersion time cause an increase in the wear rate[20].

In (2009), Ugochukwn Gregory, studied manufacturing automotive piston by employing hybrid material made from carbon fiber reinforced phenolic. The stresses arising from interference of composite piston skirt and Al cap was analyzed by using contact analysis. The empirical analysis was executed to determine tensile, compressing and flexural capabilities of the material[21].

In (2011), M. F. Khdeer., studied the influence of the weight fraction and grain size of SiO_2 on the thermal conductivity of Epoxy, used to manufacture structural parts. The results showed an increase in thermal conductivity with the increase in weight fraction and decrease with the increase in grain size of SiO_2 particles in a nonlinear relationship. The maximum difference in thermal conductivity between the unreinforced Epoxy and reinforced Epoxy was (0.445 $W/m.^{\circ}c$) at a weight fraction of (20%) and grain size of (20 μm) of SiO_2 particles. The maximum value of thermal conductivity (k= 0.61 $W/m.^{\circ}c$) at (20%) weight fraction and (20 μm)[22].

In (2012) M. Ravi Chandra et al., studied the structural and modeling analysis of weighty automotive chassis made of a polymeric composite material by three various cross-sections. They used TATA 2515EX dimensions for existing heavy automotive chassis for analysis and modeling of a weighty automotive chassis with three various composite materials i.e., Epoxy/E-glass, Epoxy/S-glass, and Epoxy/Carbon undergo to the equal pressure as that in a steel chassis. The three various composite weighty automotive chassis were modeled by considering three various cross-sections, namely I, C and Bix type cross sections. They noticed that there was a weight reduction by (73-80)%, natural frequency of polymeric composite weighty automotive chassis are (32-54)% upper than chassis of steel and (66-78)/% stiffer than the chassis of steel, and polymeric composites Epoxy/Carbon weighty automotive chassis (I-SECTION) chassis has maximum stiffness and strength and lower in weight compared with steel and the two polymeric composites and other cross-sections considered in this study[23].

In (2012), Zakaria Mouti, studied the impact strength of polyamide 66 reinforced by short fiberglass used in automotive composite structure (oil pan). The damage by the stone impact was also investigated. The simulation was performed by using LS-DYNA solver to compare the results. The results showed that the impact resistance of polyamide 66 reinforced by short fiberglass was sensitive and influenced by moisture, air oxidation, and temperature aging, and the adding ribs at the edge of the pan cause increase the stiffness and strength[24].

In (2012) Farag M. and Drai A., elucidated the influence of graphite on the mechanical and tribological behavior of (glass and polyester) composite system. The tensile strength was studied according to ASTM-D 638-87and the wear rate and wear resistance were investigated according to ASTM-D 5963 using a pin on disc machine to present the composite tribological behavior. It was proved that when the graphite filler content increased the mechanical and tribological properties behavior was improved[25].

In (2014), L. L. Myagkov, described advanced and conventional materials and manufacturing methods used for the production of modern internal combustion engines. Advanced materials include compact graphite iron, (graphite/carbon) and (carbon/carbon) fiber-reinforced polymer composites, polyamides for manufacturing intake manifolds and alloys and ceramics for manufacturing valves and other components. The results showed that the application of this materials allows engineers to create engines with reduced dimensions and increased durability[26].

In (2014), K. Kamalakar, T. Suresh P., studied the design optimization of oil pan using finite element analysis. The purpose of this study is to design a truck oil pan for vibration reduction using numerical simulations. The oil pan was studied in two different cases: pre-stress modal analysis and harmonic analysis. The first pre-stress modal analysis was performed using block lanczo's method on the oil pan and then harmonic analysis of the pre-stressed oil pan was done using full harmonic method. The results showed that the design changes increase the stiffness and it is safe for the mentioned operating loads[27].

In (2015), A.Vikram et al, elucidated the influence of different content ratios and lengths of (Epoxy composites reinforced by carbon fiber) used for high bending, strength and stiffness application in automotive and lightweight structural applications. Carbon fibers is taken in the (3%, 5% and 7 %) weight fraction with changed fiber lengths such as (1cm, 2cm, and 3cm). Thermal properties like (DSC and TGA) were investigated to show the effect of variation in fiber length on Carbon fiber with Epoxy composites. Significant improvement in tensile and flexural strengths of Epoxy composites reinforced by Carbon fiber has been observed by changed fiber lengths. Tensile strength, modulus of elasticity, Flexural strength, and modulus, increased correspondingly up to (5%)wt and (2cm) length of carbon fiber reinforced Epoxy and decreases with the further adding of fiber contents i.e., (7% wt). General studies showed that the carbon fiber reinforced composites at (2cm) length of carbon fiber and (5%)wt loading are promising candidates for structural applications where high strength and stiffness is necessary[28].

In (2015), Reddy C.V. et al., studied the effect of adding silicon dioxide (SiO_2) in different weight fraction (0, 5, 10 and 15%) on the flexural strength of glass fibers reinforced polymer composite. The reinforcement was bi-woven E-glass fibers with (0º/90º) fibers orientation, hand lay-up technique was used to prepare the samples. Experimental results showed that the composite with (10 %) of SiO_2 improved flexural strength and flexural modulus to a noticeable amount. Further increase in (SiO_2) caused a decrease in the flexural strength and flexural modulus this may be due to changes in matrix properties and reduction in their bonding strength between fiber and matrix[29].

In (2015), Jweeg et.al., designed a new athletic prosthetic foot. The foot was manufactured by using Epoxy reinforced by carbon fibers and that gives a good mechanical response. The impact tester was designed and manufactured to perform the test. For the same dropped level, the impact response of the samples with glass fiber and carbon fiber have the same peak load for different drop angle. In addition, it was clear that the responses of the sample manufactured with carbon fiber were smoother than the sample manufactured with the glass fiber[30].

In (2016), Jagadale U.S. and Raut L.B., investigated the mechanical properties (tensile strength and shear strength) of glass fibers reinforced polymeric matrix with different fibers volume fraction (40, 50 and 60%), hand lay-up and compression molding were used to prepare the samples. Results showed the better mechanical properties at volume fraction (50%), a further increase in the fiber content caused an increase in the mechanical properties[31].

1-3 Aims of the Work

The main objective of studying composite materials is to produce materials with properties capable of withstanding advanced application. The hybrid composite is prepared to study the ability to apply these composite in structural parts. Mechanical properties of the hybrid composite were studied and compared with properties of the traditional materials. The research aims at:

1. Producing blends which contain Epoxy resin type LEYCO-POX 103 with material Manufactured locally (Resole resin) by weight ratio of (10, 20, 30, 40)%, and studying the improvement in mechanical and physical Properties by adding (silica and graphite) as a filler materials and carbon fibers as a reinforced material.
2. Assessing the hybrid composite mixing processes in accordance to mechanical, physical and morphology of the blend.
3. Assessing the composite behavior under sliding wear.
4. Studying the hybrid composite absorptivity.
5. Comparing hybrid composite materials with materials used for manufacturing oil pan.
6. Studying the ability of hybrid composite blend to carry the load applied on oil pan part in automotive.

1-4 Thesis outline

The thesis is divided into five chapters:

1- Chapter one includes an introduction to composite materials and the literature review.
2- Chapter two includes theoretical parts on composites and its constituents.
3- Chapter three includes the experimental work by giving details on materials used, composite manufacturing procedure and the applied tests.
4- Chapter four includes the results and discussion of the experimental work of the composite samples and numerical analysis.
5- Chapter five includes the conclusions, recommendation and suggestions for future works.

Abstract

In this study the hybrid composite polymeric materials were studied to investigate the usage in structure applications. Initially, blending which contained (Epoxy resin and Resole resin) were prepared with many weight fraction (60%-40%, 70%-30%, 80%-20% and 90%-10%) respectively. The blends were tested mechanically (tensile, hardness and impact) to investigate the mechanical properties and choose the blend to reinforce it.

The blend (ER3) which contained (80%Epoxy+ 20%Resole) was chosen to prepare hybrid composite materials because it has good mechanical properties compared with the blends (70%Epoxy+ 30%Resole) and (60%Epoxy+ 40%Resole). It is also lower in cost compared with the blends (90%Epoxy+ 10%Resole) which have the best value of tensile strength, hardness and impact strength.

The mechanical and physical properties of hybrid composite blends which contain carbon fiber as a reinforcement material and (silica & graphite) as a filler materials, were investigated and compared with blend ER3 (80%Epoxy+ 20%Resole) which is considered as a reference material in this study.

Hybrid blends contain (20%) weight fractions of carbon fiber in three hybrid blends and (silica, graphite) was (16%, 0%), (0%, 16%) and (8%, 8%) respectively. Ultimate tensile strength, hardness, Impact strength, flexural strength, max. shear stress and thermal conductivity were increased while wear resistance decreased in blends (16%silica) and (16%graphite) compared with reference blend ER3. The absorptivity of oil was very small and have almost the same values in hybrid composite blends and reference blend.

To investigate that the hybrid composite blends was usable in oil pan, the results were compared with material used to manufacture oil pan. The results give

convergence in mechanical properties of hybrid composite blends with oil pan material.

Numerical analysis (finite element) was carried out by using ANSYS program and modeling was done by using three dimensional program (SOLIDWORK 2016) then imported to ANSYS. The element type of SOLID 45 was used in this program. In modeling this element, the linear isotropic model was used for simulating the stress and deformation for four blends when internal static pressure is applied in oil pan part. The results proved that the hybrid composite blends have the ability to carry the load applied on oil pan without failure and with minimum deflection.