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Assessment of sandwich panels in construction Industries

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الخلاصة :

الألواح المركبة أصبحت تحظى بشعبية متزايدة في الأعمال والتطبيقات الهندسية نتيجة لقوتها ولصلابتها العالية وخفتها ووزنها النسبي. المواد الطويلة العمر دائما ما تكون مرغوبة من مهندسي الإنشاءات .

مواد الألواح ذات المنشأ البلاستيكي الحراري يتم مزجها مع الألياف الزجاجية أو مع الألياف الكربونية لإنتاج نوع من الحشو المركب يستعمل في الألواح المركبة والذي أصبح الآن يمثل مواد إنشاءات في العلوم الهندسية وفي قطع غيار المركبات في السنوات الأخيرة وهذا أيضاً بسب خفة وزنها وخاصية مقاومة التآكل.

وبرغم إن الألياف الكربونية المقواة بالبوليمير تلبي المطالب إلا أن تباينها يجعل توصيلات العناصر الإنشائية ضعيفة إلى حد كبير وهو السبب الرئيسي من وراء عدم استعمال قوته العالية بالكامل.

ولكن الوجه السفلي للصفيحة مصنوع من البولي بروبليين بنسبة 30 % ألياف زجاجية و1% ألياف كربونية بينما الصفائح المركبة مصنوعة من قشرة خارجية رقيقة من ألياف البوليمير المقواة والذي يربط باللصق بقالب رغوة أكثر سمكاً.

المواد المركبة في الألواح المحشوة تطلب معرفة السلوك الميكانيكي للمواد المستخدمة للواجهات والقالب.

في هذا العمل سوف يتم استعمال نماذج رياضية مختلفة لتقييم التحليل الإنشائي للألواح المحشوة .

نتائج الدراسة التجريبية بينت إن المركبات البلاستيكية الحرارية المقواة سوف تكون لها فوائد كبيرة للإنشاءات في المستقبل.

Abstract:

Composite sandwich plates are gaining increasing popularity in engineering practice, due to their – strength, high – stiffness – to – light – weight ratio. Durable materials are always desired by structure engineer. Composite materials of thermoplastics origin are blended with fiber glass or carbon fiber to produce a sandwich type composite, used in sandwich panels is now becoming the structural material in engineering sciences and automobile parts in recent years also due to its light – weight and anti – corrosion properties. Although carbon fiber reinforced-polymer meets the demands, but its anisotropy makes the connection of structural elements considerably weak which is the main cause that make its high strength not be utilized fully. However, the lower face lamina, the top face are made of polypropylene with (30%) fiber glass or (1%)carbon fiber composite, sandwich laminates are made of thin outer skin of fiber reinforced polymer adhesively bonded to a thicker core of foam. Composite materials in sandwich panels require knowledge of the mechanical behavior of the materials used for the facings and the core. In this work, different mathematical models will be used to evaluate structural analysis of the sandwich panels. The results of the experimental study have showed that reinforced thermoplastics composite will have potential benefits for the structures in future.

1. Introduction :

Sandwich panels are composite structural elements, consisting of two thin, stiff, strong faces separated by a relatively thick layer of low-density and stiff material. The faces are commonly made of steel, aluminum, hardboard or gypsum and the core material may be polyurethane, polyisocyanate, expanded polystyrene, extruded polystyrene, phenolic resin, or mineral wool. In Australia, sandwich panels are commonly made of expanded polystyrene. Sandwich construction has been widely used in aircraft and many structural applications for a long time. In recent years, sandwich panels are increasingly used in building structures particularly as roof . They are also being used as internal walls and ceilings. However, research and development of sandwich panels with profiled faces began only in late 1960s . Due to the increasing interest in the use of structural sandwich panels ,a good deal of research has continued in recent years .

2. The origins Of Sandwich Technology :

The first successful landing of a space ship on the moon on 20th. July 1969 was the result of the successful application of a number of new technologies including rocketry , computers and sandwich construction .Although public interest catered on rocketry and computer technology , it was only with the help of sandwich technology that a shell of the spacecraft could be constructed that was light in weight and yet strong enough to sustain the stresses of acceleration and landing . figure 1 shows the wall construction of the Apollo capsule which consisted of two interconnected sandwich shells. Figure 2 shows details of the outer shell, which comprised two thin steel facings and a honeycomb core. The inherent advantage of sandwich construction is immediately apparent, namely, high strength and rigidity at low weight.

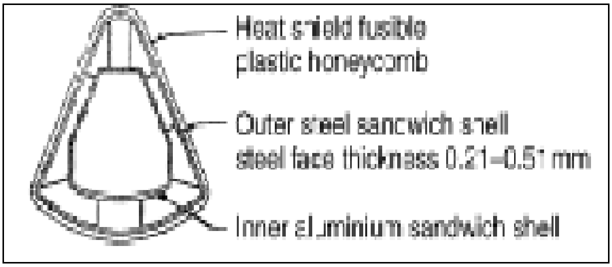


Figure1 Sandwich construction of the Apollo capsule.

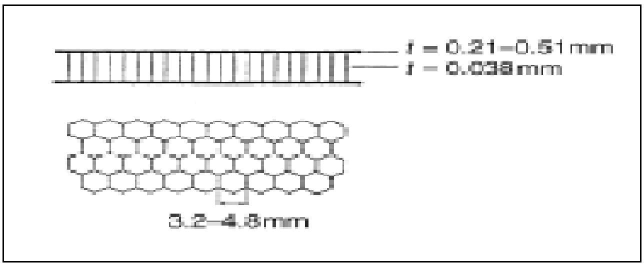
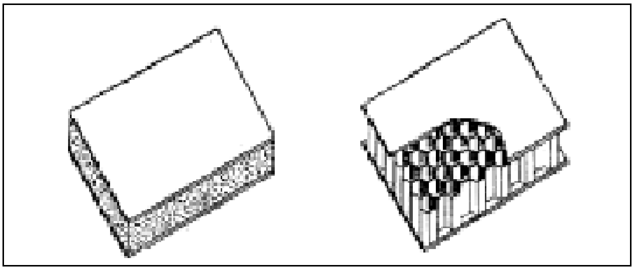


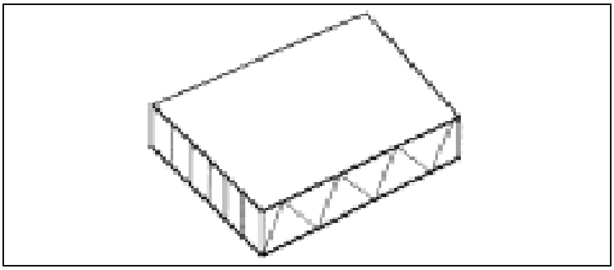
Figure 2 Cellular sandwich forming the outer shell of the Apollo capsule.

3. Principles of Sandwich Construction :

The structure of sandwich panels always follows the same basic pattern. Two facings, which are relatively thin and of high strength, enclose a core which is relatively light and which has adequate stiffness in a direction normal to the faces of the panel. A great many alternative forms of sandwich construction may be obtained by combining different facing and core materials. as shown in figure 3.



(a) Expanded plastic core.   (b) Honeycomb core.



(c) Mineral wool core.

Figure 3 sandwich construction with different cores.

The resulting composite panel owes its success to the following favorable properties:

- high load-bearing capacity at low weight.
- excellent and durable thermal insulation.
- absolute water and vapor barrier.
- excellent air tightness.

- surface finished facings providing resistance to weather and aggressive environments. Capacity for rapid erection without lifting equipment; easier installation in hostile weather conditions.

Facing Materials :
Relatively thin, high-strength sheets are generally used as facing materials.
Steel facings :
Thin steel sheets are the most frequently used facing material. In general, only sheets with both metallic and organic (plastic) coatings should be used.
Aluminum sheeting :
Sandwich panels with facings made of bare aluminum sheet are sometimes used in applications where there are special requirements for corrosion resistance or hygiene; for example, in the production or storing of foodstuffs.
Composite materials:
Composite materials consist of two or more materials combined in such a way that the individual materials are easily distinguishable. The individual materials that make up a composite are called constituents.

4.1 Constituents of Composite Materials:
Matrix :
Phase that receive the inserts in phase composition is continuous phase and is called as matrix. It is also called as binders .Ex- Polymer, Ceramics, Metals.
Polymers:
Polymers used for auto body applications may be split into thermoplastics and thermosets.
Thermoplastic Polymers :
Thermoplastics can be divided into amorphous and crystalline varieties. In amorphous forms the molecules are orientated randomly.
Thermosetting Polymers :
Thermosets are generally more brittle than thermoplastics so they are often used with fiber reinforcement of some type.
Reinforcement:
Fibers are the principle constituents in fiber reinforcement composite materials.

Glass fiber :

Glass fiber are the oldest form of strength fiber used in composite structure materials.

Carbon fiber:

Nowadays carbon fibers finds its own place in the composite materials where weight reduction are valuable.

Figure 4 and Figure 5 show the main components in the extruder coupled with injection moulding machine .

5. Experimental Work :

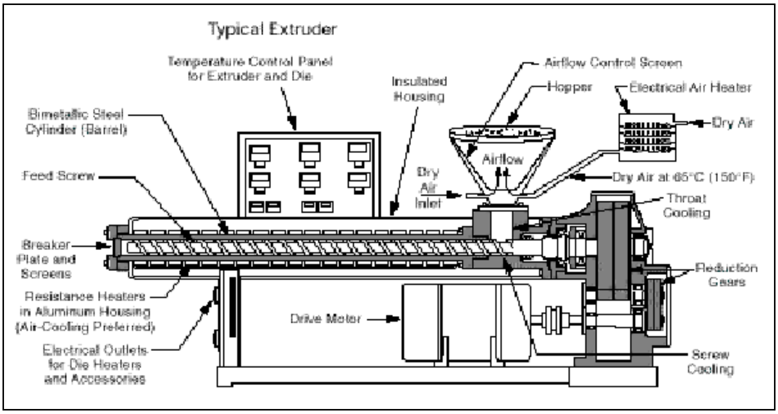


Figure 4 Rabta Extruder.

6. Injection Moulding Process :

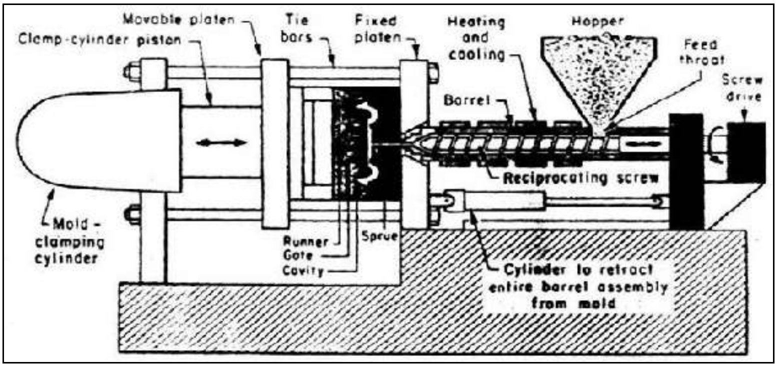


Figure 5 Extruder coupled with injection moulding.

7. Result And Discussion :-

Fiber Mass Fraction :

Fiber mass fraction is defined as:

$$M_f = \text{Mass of fibers} / \text{Total mass}$$

In consequence, the mass of matrix is:

$$M_m = \text{Mass of matrix} / \text{Total mass}$$

With : $M_m = 1 - M_f$

Fiber Volume Fraction :

Fiber volume fraction is defined as:

$$V_f = \text{Volume of fiber} / \text{Total volume}$$

As a result, the volume of matrix is given as:

$$V_m = \text{Volume of matrix} / \text{Total volume}$$

With : $V_m = 1 - V_f$

Mass Density of a Ply :

The mass density of a ply can be calculated as :

$$\rho = \text{total mass} / \text{Total volume}$$

The above equation can also be expanded as:

$$\rho = \frac{\text{mass of fiber}}{\text{total volume}} + \frac{\text{mass of matrix}}{\text{total volume}}$$
$$= \frac{\text{volume of fiber}}{\text{total volume}}\rho_f + \frac{\text{volume of matrix}}{\text{total volume}}\rho_m$$

Theoretical calculations for strength, modulus, and other properties of a fiber reinforced composite are based on the fiber volume fraction in the material.

Experimentally, it is easier to determine the fiber weight fraction Mf, from which the fiber volume fraction vf and composite density ρc can be calculated :

$$\rho c = vf \times \rho f + vm \times \rho m$$

Mechanics of fiber-reinforced composites :

The mechanics of materials deal with stresses, strains, and deformations in engineering structures subjected to mechanical and thermal loads.

As a result, the mechanics of fiber-reinforced composites are far more complex than that of conventional materials. The mechanics of fiber-reinforced composite materials are studied at two levels:

1. The micromechanics level, in which the interaction of the constituent materials is examined on a microscopic scale. Equations describing the elastic and thermal characteristics of a lamina are, in general, based on micromechanics formulations. An understanding of the interaction between various constituents is also useful in delineating the failure modes in a fiber-reinforced composite material.

2. The macro mechanics level, in which the response of a fiber-reinforced composite material to mechanical and thermal loads is examined on a macroscopic scale. The material is assumed to be homogeneous. Equations of orthotropic elasticity are used to calculate stresses, strains, and deflections .

8. Compliance And Stiffness Matrices :

Specially Orthotropic Lamina (θ = 0° or 90°) :

$$\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{xy} \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{21}(=s_{12}) & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} \begin{bmatrix} \sigma_{xx} \\ \sigma_{xy} \\ \tau_{xy} \end{bmatrix} = [S] \begin{bmatrix} \sigma_{xx} \\ \sigma_{xy} \\ \tau_{xy} \end{bmatrix}$$

where :

$$S_{11} = \frac{1}{E_{11}}$$

$$S_{12} = S_{21} = -\frac{V_{12}}{E_{11}} = -\frac{V_{21}}{E_{22}}$$

$$S_{22} = \frac{1}{E_{22}}$$

$$S_{66} = \frac{1}{G_{12}}$$

$$\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \tau_{xy}\end{bmatrix}=\begin{bmatrix}Q_{11} & Q_{12} & 0\\ Q_{21}(=Q_{12}) & Q_{22} & 0\\ 0 & 0 & Q_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \gamma_{xy}\end{bmatrix}=[Q]\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \gamma_{xy}\end{bmatrix}$$

Where [Q] represents the stiffness matrix for the specially orthotropic lamina.

Various elements in the [Q] matrix are :

$$Q_{11}=\frac{E_{11}}{1-V_{12}V_{21}}$$

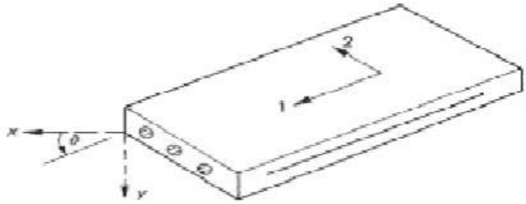
$$Q_{22}=\frac{E_{22}}{1-V_{12}V_{21}}$$

$$Q_{12}=Q_{21}=\frac{V_{12}E_{22}}{1-V_{12}V_{21}}=\frac{V_{21}E_{11}}{1-V_{12}V_{21}}$$

$$Q_{66}=G_{12}$$

The strain–stress relations for a general orthotropic lamina, can be expressed in matrix notation as:

$$\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \gamma_{xy}\end{bmatrix}=\begin{bmatrix}\bar{S}_{11} & \bar{S}_{12} & \bar{S}_{16}\\ \bar{S}_{12} & \bar{S}_{22} & \bar{S}_{26}\\ \bar{S}_{16} & \bar{S}_{26} & \bar{S}_{66}\end{bmatrix}\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \tau_{xy}\end{bmatrix}=[\bar{S}]\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \tau_{xy}\end{bmatrix}$$



Expressing stress in the x ,y coordinate system in terms of stresses in the 1,2 coordinate system in the following way , shear strain must be used in the transformation:

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix} = \begin{bmatrix} m^2 & n^2 & -2mn \\ n^2 & m^2 & 2mn \\ mn & -mn & m^2-n^2 \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix}$$

where : m = cos(θ) , and n = sin(θ).

$$\{\sigma_{xy}\} = [T]\{\sigma_{12}\}$$

$$\{\sigma_{xy}\} = [T]\{\varepsilon_{12}\} = [T][Q][T]^{-1}\{\varepsilon_{xy}\} = [\bar{Q}]\{\varepsilon_{xy}\}$$

$$\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{bmatrix} = \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{bmatrix}$$

where [Q] represents the stiffness matrix for the lamina. Various elements in the [Q] matrix are expressed in terms of the elements in the [Q] matrix as :

$$\bar{Q}_{11} = Q_{11}\cos^4\theta + 2(Q_{12} + 2Q_{66})\sin^2\theta\cos^2\theta + Q_{22}\sin^4\theta,$$
$$\bar{Q}_{12} = Q_{12}(\sin^4\theta\cos^4\theta) + (Q_{11} + Q_{22} - 4Q_{66})\sin^2\theta\cos^2\theta,$$
$$\bar{Q}_{22} = Q_{11}\cos^4\theta + 2(Q_{12} + 2Q_{66})\sin^2\theta\cos^2\theta + Q_{22}\sin^4\theta,$$
$$\bar{Q}_{16} = (Q_{11} - Q_{12} - 2Q_{66})\sin\theta\cos^3\theta + (Q_{12} - Q_{22} + 2Q_{66})\sin^3\theta\cos\theta,$$
$$\bar{Q}_{26} = (Q_{11} - Q_{12} - 2Q_{66})\sin^3\theta\cos\theta + (Q_{12} - Q_{22} + 2Q_{66})\sin\theta\cos^3\theta,$$
$$\bar{Q}_{66} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66})\sin^2\theta\cos^2\theta + Q_{66}(\sin^4\theta\cos^4\theta).$$

Using the same matrix manipulation, the reduced compliance matrix can be generated as follows :

[Ŝ] = [Q] -1

$$\begin{Bmatrix} \in_x \\ \in_y \\ \in_{xy} \end{Bmatrix} = \begin{bmatrix} \bar{S}_{11} & \bar{S}_{12} & \bar{S}_{16} \\ \bar{S}_{12} & \bar{S}_{22} & \bar{S}_{26} \\ \bar{S}_{16} & \bar{S}_{26} & \bar{S}_{66} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix}$$

These expressions are :

$$\bar{S}_{11} = \frac{1}{E_{xy}} = S_{11}\cos^4\theta + (2S_{12} + S_{66})\sin^2\theta\cos^2\theta + S_{22}\sin^4\theta,$$

$$\bar{S}_{12} = -\frac{\nu_{xy}}{E_{xx}} = S_{12}(\sin^4\theta + \cos^4\theta) + (S_{11} + S_{22} - S_{66})\sin^2\theta\cos^2\theta,$$

$$\bar{S}_{22} = \frac{1}{E_{yy}} = S_{11}\sin^4\theta + (2S_{12} + S_{66})\sin^2\theta\cos^2\theta + S_{22}\cos^4\theta,$$

$$\bar{S}_{16} = -m_x = (2S_{11} - 2S_{12} - S_{66})\sin\theta\cos^3\theta - (2S_{22} - 2S_{12} - S_{66})\sin^3\theta\cos\theta,$$

$$\bar{S}_{26} = -m_y = (2S_{11} - 2S_{12} - S_{66})\sin^3\theta\cos\theta - (2S_{22} - 2S_{12} - S_{66})\sin\theta\cos^3\theta,$$

$$\bar{S}_{66} = \frac{1}{G_{xy}} = 2(2S_{11} + 2S_{22} - 4S_{12} - S_{66})\sin^2\theta\cos^2\theta + S_{66}(\sin^4\theta + \cos^4\theta).$$

Figure 6 and Figure 7 show variation of properties in unidirectional composite as a function of fiber angle for a single ply of Polypropylene with (30%) Fiber glass and (1%) Carbon Fiber composite respectively .

Figure 3,6 shows the variation of the moduli and Poission ratio values for all angles between (0 and 90 0). This gives a clear picture of the performance of unidirectional composites when subjected to off-axis loading , Figure 3,6 represents the results for Polypropylene and fiber glass blend .The reinforced mixture of Polypropylene and carbon fiber is shown in figure 3,7 .

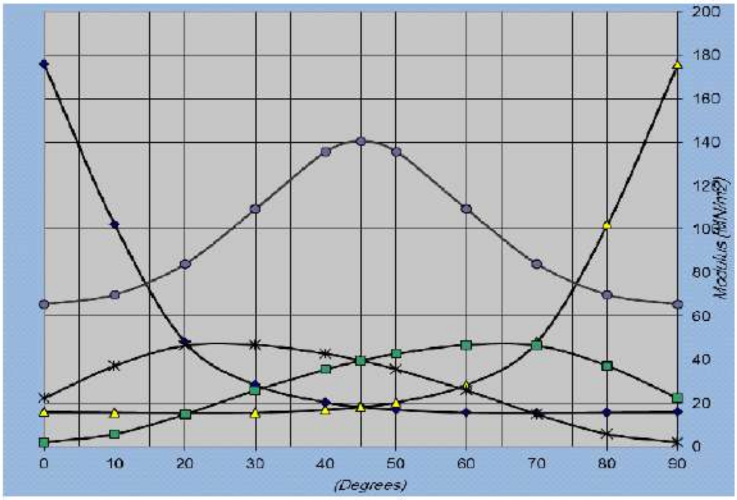


Figure 6 Variation of elastic properties for a single ply of Polypropylene with (30%) Fiber glass composite.

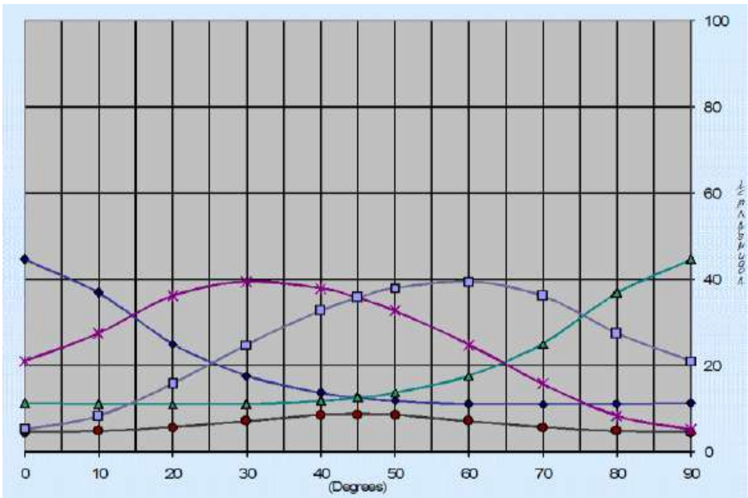


Figure 7 Variation of elastic properties for a single ply of Polypropylene with (1%) Carbon Fiber composite.

9. Conclusion :

Sandwich panels has future to replace conventional metals in airspace, automobile and building industries due to their light weight and energy saving and carbon dioxide low emissions.

Most structures are not loaded in a single directions. The orientation of sandwich panels are in multiple directions stacking the multiple phase together and enhancing the major mechanical properties.

Stress strain correlations of composite materials made from polypropylene reinforced by fiberglass or carbon fiber are shown superiority and are in the range of applications in the field of airspace, automobile and building industries.

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Theoretical Study Of Some Combustion Parameters On Performance Of Internal Combustion Engines.

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الملخص :

أجريت دراسة تأثير بعض المتغيرات الخاصة بالوقود على كفاءة محرك احتراق داخلي، حيث تم دراسة كفاءة احتراق الوقود ونسبة خلط الهواء إلى الوقود وكذلك نسبة الحرارة النوعية على قدرة وكفاءة المحرك. تم حساب تأثير هذه المتغيرات على الأداء والقدرة الناتجة لمحرك أوتو لعدة نسب انضغاط مختلفة.

Abstract:

A study of gas cycles as the models of internal combustion engines is useful for illustrating some of the important parameters influencing engine performance. In this paper the effect of combustion efficiency, specific heat ratio, and equivalence ratio on the variation on performance with compression ratio for Otto engine. By using Excel program the characteristic curves of the power output and thermal efficiency versus compression ratio are obtained.

The results show that the power output, the thermal efficiency, the optimal compression ratio corresponding to maximum power output point, the optimal compression ratio corresponding to maximum thermal efficiency point. The performance characteristic curves of the cycle are presented. Moreover, the effect of combustion efficiency, specific heat ratio, and equivalence ratio on the cycle performance were analyzed. The results show that the effect of combustion efficiency, specific heat ratio, and equivalence ratio on the cycle performance are significant. The results of this investigation are of importance when considering the designs of actual Otto engines.

1. Introduction:

A heat engine is a machine which converts heat energy into mechanical energy. The combustion of fuel such as coal, petrol, diesel generates heat. This heat is supplied to a working substance at high temperature. By the expansion of this substance in suitable machines, heat energy is converted into useful work. Heat engines can be further divided into two types:

- External combustion .
- Internal combustion .

External combustion type in which the working fluid is entirely separated from the fuel- air mixture (ECE), and the internal combustion (ICE) type, in which the working fluid consists of the products of combustion of the fuel- air mixture itself.

Chemical energy of the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the engine. This thermal energy raises the temperature and pressure of the gases within the engine and the high-pressure gas then expands against the mechanical mechanisms of the engine. This expansion is converted by the mechanical linkages of the engine to a rotating crankshaft, which is the output of the engine. The crankshaft, in turn, is connected to a transmission and/or power train to transmit the rotating mechanical energy to the desired final use. For engines this will often be the propulsion of a vehicle (i.e., automobile, truck, locomotive, marine vessel, or airplane).

Most internal combustion engines are reciprocating engine shaving pistons that reciprocate back and forth in cylinders internally within the engine.

The objective of this study is to examine of the some of the dominant effective parameters in combustion on performance of air standard Otto cycle.

2. Air-standard Otto cycle:

The Otto cycle is the ideal cycle for spark ignition, reciprocating engines. The thermodynamic analysis of four-stork cycle can be simplified if the air standard assumptions are used. The Otto cycle consists of four internally reversible processes as shown in figure (1).

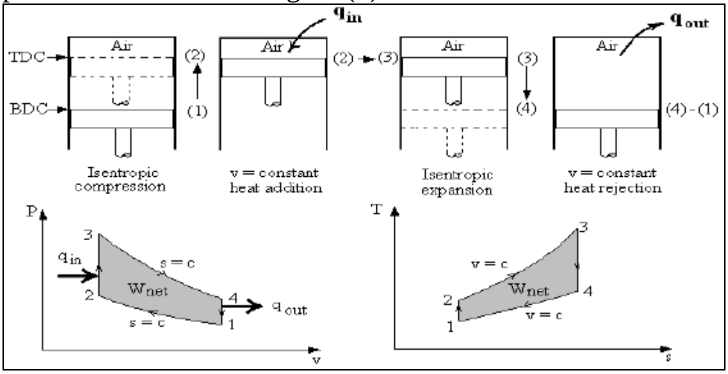

Figure (1) Otto cycle and P-v, T-s diagrams

The Otto cycle is executed in a closed system and the change of kinetic and potential energies are disregarded. The energy balance for any of the processes is expressed in a unit mass basis as,

- Process 1→2, isentropic compression

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} \rightarrow (1)$$

$$r = \frac{V_1}{V_2} \rightarrow (2)$$

Where: T is the temperature (°K).
k is the specific heat ratio.
V is the volume (m3).
R is the compression ratio.

$$\therefore \frac{T_2}{T_1} = r^{(k-1)} \rightarrow (3)$$

- Process 2→3, constant volume heat addition,

$$V_2 = V_3,$$

$$Q_{in} = \dot{m}_t . c_v (T_3 - T_2) \rightarrow (4)$$

Where: Q_{in} is the inlet energy (W).

$\dot{m}_t$ is the total mass flow rate (kg/sec).

c_v is the specific heat volume (kJ/kg.°K).

When the total energy of the fuel is utilized, the maximum cycle temperature reaches undesirably high levels with regard to structural integrity. Hence, engine designer intend to restrict the maximum cycle temperature, the total energy of the fuel per second input into the engine can be given by :

$$Q_{fuel} = \eta_c . \dot{m}_f . Q_{LHV} \quad \rightarrow (5)$$

Where: η_c is combustion efficiency.

$\dot{m}_f$ is fuel mass flow rate (kg/sec).

Q_{LHV} is lower heating value of fuel (kJ/kg).

Assumed to be the heat add to working fluid:

$$Q_{fuel} = Q_{in} \quad \rightarrow (6)$$

The relation between $\dot{m}_f$ and $\dot{m}_t$ is defined as :

$$\dot{m}_t = \dot{m}_f \left(1 + \frac{(m_a/m_f)_s}{\emptyset} \right) \rightarrow (7)$$

The relation between combustion efficiency and equivalence ratio is :

$$\eta_c = \eta_{c,max} \left(-1.6082 + \frac{4.6509}{\emptyset} - \frac{2.0764}{\emptyset^2} \right) \rightarrow (8)$$

Where: $\emptyset$ is equivalence ratio.

$\frac{m_a}{m_f}$ is the air fuel ratio.

And the subscript (S) denotes stoichiometric conditions.

- Process 3→4, isentropic expansion,

$$\dot{m}_t = \dot{m}_f \left(1 + \frac{(m_a/m_f)_s}{\emptyset}\right) \rightarrow (7)$$

$$r = \frac{V_1}{V_2} = \frac{V_4}{V_3} \rightarrow (10)$$

$$\therefore \frac{T_3}{T_4} = r^{(k-1)} \rightarrow \quad (11)$$

- Process 4→1, constant volume heat rejection, ,

$$V_4 = V_1$$

$$Q_{out} = \dot{m}_t c_v (T_4 - T_1) \rightarrow (12)$$

Where: Q_{out} is outlet energy (W).

Otto cycle net work done or power is,

$$P_{otto} = Q_{in} - Q_{out} \rightarrow \quad (13)$$

Where: P_{otto} is power of Otto cycle (W).

The thermal efficiency of Otto cycle is,

$$\eta_{th,Otto} = \frac{P_{otto}}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}} \rightarrow (14)$$

$$\therefore \eta_{th,Otto} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \rightarrow (15)$$

3.Constants and parameters used in the study:

The values of the constant and the parameters used in this study are summarized in table [1].

Table (1) constants and parameters used in the study [3], [7]

$\dot{m}_f$	0.001 kg/sec
R	0.287 kJ/kg .k
Q_{LHV}	45000 kJ/kg
$(m_a/m_f)_s$	14.5
T_1	300 K
r	1 – 100
η_c	80 - 100%
K	1.4 , 1.3 , 1.2
$\emptyset$	1, 0.6 ,1.3

4. Results and discussions :

The thermal efficiency and the power output of the Otto cycle are dependent on the combustion efficiency, specific heat ratio and equivalence ratio. In order to illustrate the effect of these parameters, the relations between the power output and the compression ratio and between the thermal efficiency and the compression ratio of the cycles are presented in following figures.

4.1 Effects of the combustion efficiency on the cycle performance :

The effect of the combustion efficiency on combustion temperature is as shown in figure (2), as is evident in the figure, the combustion temperature increases with increasing combustion efficiency.

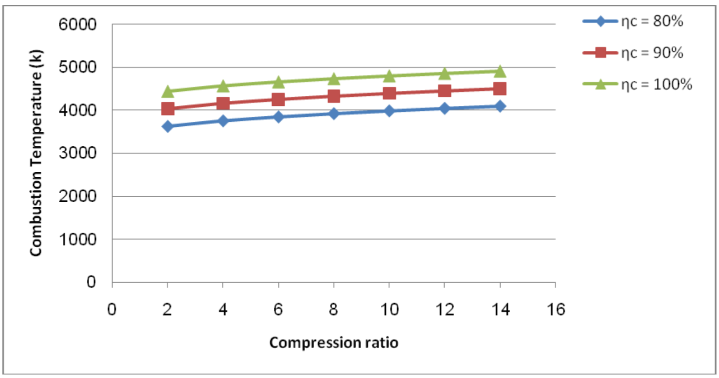

Figure (2) Effect of combustion efficiency on the variation of the combustion temperature with compression ratio.

Figures (3) and (4), show the effects of the combustion efficiency on the power output and the thermal efficiency of the cycle without heat resistance and friction losses. From figures (3), it can be seen that the combustion efficiency plays an important role on the power output of the Otto engine. They reflect the performance characteristics of an Otto cycle engine.

The variation of the power output with respect to the compression ratio and the combustion efficiency are indicated in figure (3). It can be concluded that, through the compression ratio range, the power output increase with the increasing combustion efficiency.

Therefore, it can be resulted that the effect of combustion efficiency on the power output of the cycle is related to compression ratio. It should be noted that the increase of the value of maximum power output with increasing combustion efficiency is due to the increase in the ratio of the heat added to the heat rejected.

In this case, when combustion efficiency increases by about 20%, the power output increase 20%.

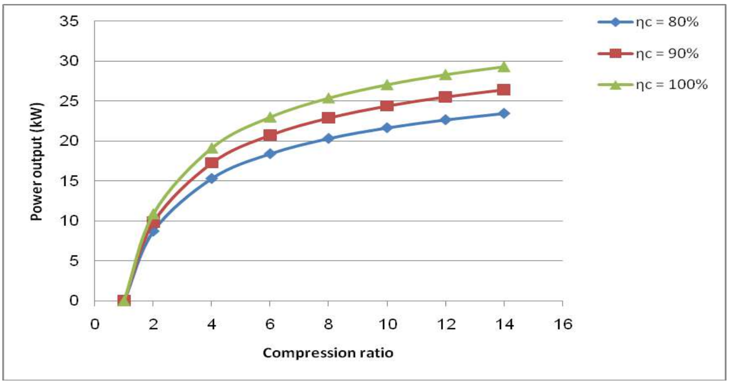

Figure (3) Effect of combustion efficiency on the variation of the power output with compression ratio.

Figure (4) shows the effect of combustion efficiency on thermal efficiency with respect to the compression ratio. It can be seen that the thermal efficiency increase with increasing compression ratio. The thermal efficiency is equal at all different combustion efficiency.

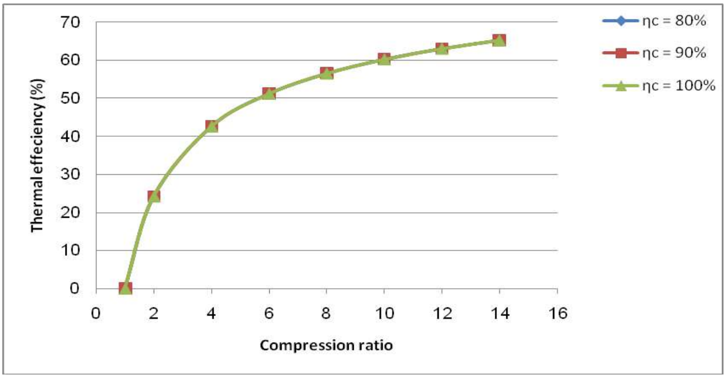

Figure (4) Effect of combustion efficiency on the variation of the thermal efficiency with compression ratio.

4-2 Effects of the specific heat ratio on the cycle performance :

The effect of the specific heat ratio on combustion temperature is as shown in figure (5), as is evident in figure, the combustion temperature increases with increasing specific heat ratio.

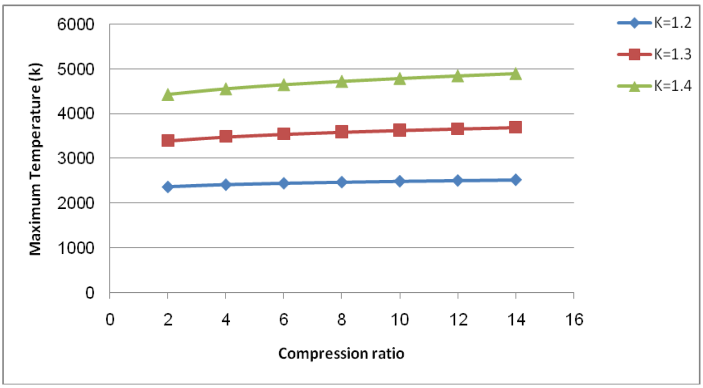

Figure (5) Effect of specific heat ratio on the variation of the combustion temperature with compression ratio.

Figures (6) and (7), show the effects of the specific heat ratio on the cycle performance without heat resistance and friction losses. From these figures, it can be found that the specific heat ratio plays an important role on the performance of the Otto engine. It is clearly seen that the effects of specific heat ratio on the performance of the cycle is related to compression ratio. They reflect the performance characteristics of an Otto cycle engine.

It can be concluded that, through the compression ratio range, the power output and thermal efficiency increase with the increasing specific heat ratio. This can be attributed to the fact that the difference between heat added and heat rejected increase with the increasing specific heat ratio. From these figures, it can be resulted that the power output and the thermal efficiency increase about 46.8% and 46.5% when specific heat ratio increases 14%.

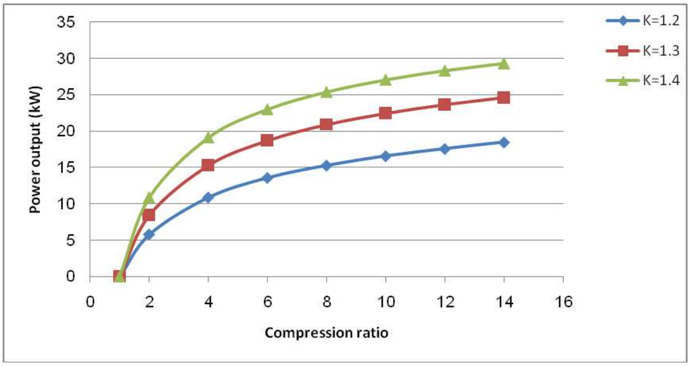

Figure (6) Effect of specific heat ratio on the variation of the power output with compression ratio.

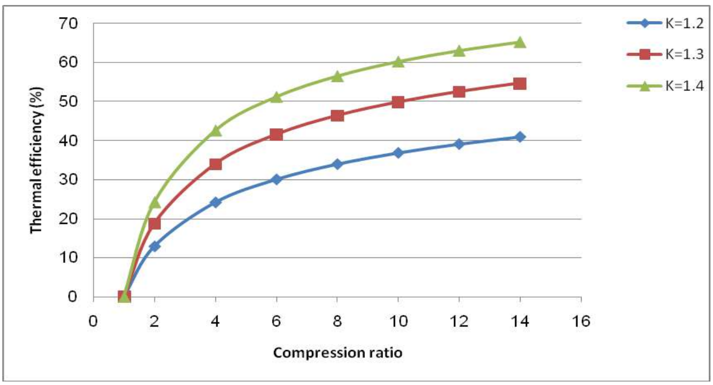

Figure (7) Effect of specific heat ratio on the variation of the thermal efficiency with compression ratio.

4-3 Effects of the equivalence ratio on the cycle performance :

The effect of the equivalence ratio on combustion temperature is as shown in figure (8), as is evident in figure, the combustion temperature increases with increasing equivalence ratio.

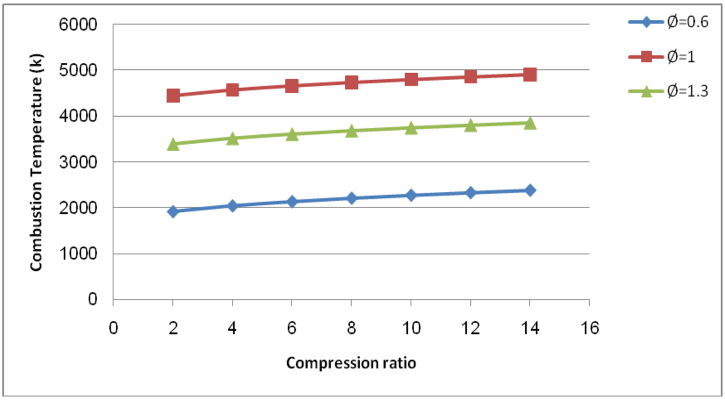

Figure (8) Effect of equivalence ratio on the variation of the combustion temperature with compression ratio.

Figures (9) and (10), show the effect of the equivalence ratio on the cycle performance without heat resistance and friction losses. From these figures, it can be found that the equivalence ratio plays an important role on the performance of the Otto engine. It is clearly seen that the effects of equivalence ratio on the performance of the cycle is related to compression ratio. They reflect the performance characteristics of an Otto cycle engine.

The power output and thermal efficiency increase with the increasing compression ratio. Figure (9) and figure (10) show that the power output and the thermal efficiency increase with increasing equivalence ratio up to about Ø=1 where they reach their peak value. This can be attributed to the fact that the ratio of the heat added by the working fluid increase with increasing equivalence ratio. With further increase in equivalence ratio, the

power output and the thermal efficiency start to decline as the equivalence ratio increases. It can be attributed to the decrease in the ratio of the heat added by the working fluid to the heat rejected by the working fluid. The calculations shows that for any same compression ratio, the smallest power output and the smallest thermal efficiency are for Ø=0.6 and the largest power output and the largest thermal efficiency are for Ø=1 when the equivalence ratio increases from Ø=0.6 to Ø=1.3.

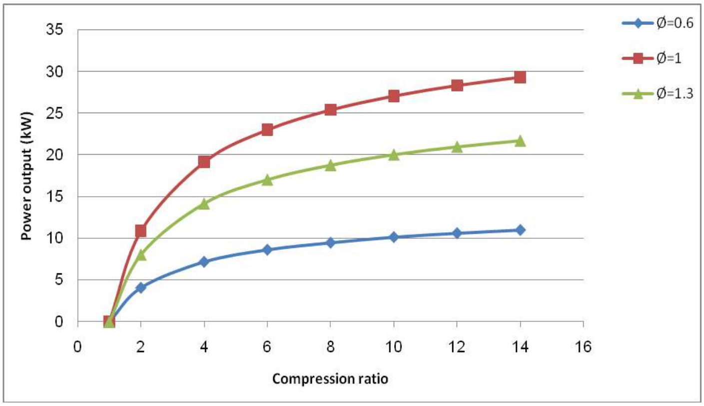

Figure (9) Effect of equivalence ratio on the variation of the power output with compression ratio.

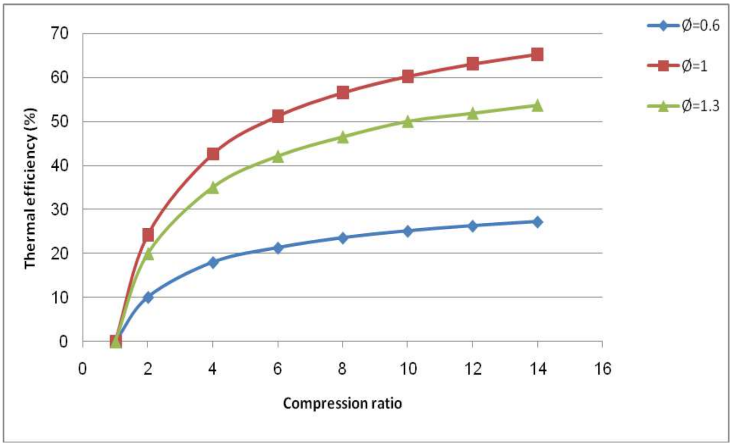

Figure (10) Effect of equivalence ratio on the variation of the thermal efficiency with compression ratio.

5.Conclusion :

This paper shows the outcome of an assessment study the effect of combustion efficiency, specific heat ratio and equivalence ratio on power output and thermal efficiency of an Otto engine cycle.

The general conclusions drawn from the results of this work are as follows:-

- Throughout the compression ratio range, the power output increase with increasing combustion efficiency, specific heat ratio, and equivalence ratio.
- Throughout the compression ratio range, the thermal efficiency increase with the increasing specific heat ratio and equivalence ratio.
- The thermal efficiency is equal at all different combustion efficiency.
- The power output and the thermal efficiency increase with increasing equivalence ratio up to about Ø =1 where they reach their peak value, and with further increase in equivalence ratio, the power output and the thermal efficiency start to decline as the equivalence ratio increases.

The results of this investigation are of importance when considering the design of actual Otto engines.

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Surface Roughness Effect on the Fatigue Lifetime of SLM Stainless Steel (316L) Parts.

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الملخص :

كل المواد الهندسية تتمتع بخواص ميكانيكية خاصة بها مثل المتانة، الاجهاد، الانفعال،الصلابة و غيرها. هذا ومن الملاحظ إن هذه الخواص تتأثر مباشرة بجودة الاسطح وخشونتها وخصوصا في حالة الاحمال المتكررة مثل اختبار الكلل. ونظراً للتقدم العلمي في مجال الصناعة الحديثة أصبحت تقنيات التصنيع بالليزر تلعب دوراً مهماً في تصنيع القطع المعقدة، والتي لاتزال تعاني من بعض العيوب مثل خشونة الاسطح للمنتج والذي يتراوح من 10 الى 30 ميكرون .

في هذا البحث تم إنتاج العينات المصنوعة من مادة الستانلستيل (316 L) وتجهيزها على آلة الليزر (SLM 125). حيث تم تقييم الأداء الميكانيكي للعينات تحت اختبار الكلل بعدما تعرضت العينات الى مرحلتين من مراحل تحسين خشونة السطح وهما على الترتيب (إعادة معالجة السطح بالليزر والتلميع بواسطة التحليل الكهربي). تم اختبار العينات باستخدام آلة اختبار الكلل(HSM 20) ومقارنة النتائج علي منحنى (S-N). حيث أظهرت النتائج تحسناً في الأداء الميكانيكي للعينات ليصل إلى حوالي 50% مع تحسن في خشونة السطح للعينات.

Abstract:

In the realm of scientific materials, all kinds of metals have natural properties such as mechanical strength, strain, and hardness etc. However, the surface roughness of a materialcan has effects on product quality and mechanical performance, such as fatigue, creep and corrosion resistance. Additive manufacturing technologies such SLM has offereda new design possibilityin terms of industrial application, but the product still suffer from poor surface roughness which ranges from 10-

30microns. Therefore, good control of the SLM process and post-process is necessary to decrease the range of surface roughness. Moreover, knowledge about dynamic mechanical behavior is still lacking due to process parameter changes.
The main aim of this study is to assess the performance(fatigue lifetime) of SLM stainless steel (316L) parts subjected to two different stages of surface finish method, namely laser re-melting and electro-polishing. The samples under various surface toughness and after applying the above stages of surface finish were tested by using a fatigue tester (HSM 20).Also the S-N curve of the samples was plotted and the results reveal about 50% of total improvement in fatigue lifetime.

1- Introduction:

Failure of a material occurs when a large amount of stress is concentrated at a fixed point, although the maximum stress applied at that point may be below the yield stress. This phenomenon is known as fatigue. In such case, the tensile stresses at a microscopic point are applied leading to encourage cracks to initiate starting from the edge and continue increasing.Once the stresses have been initiated,this helps to develop the crack until the reduction of section and has lost its potential to carry the applied load.It is worth mentioning that all materials suffer fatigue but that this varies. Endurance limit stress is known as fatigue limit. For instance, mild steel stress levels are set at a level below which the fatigue fracture will not occur.The steel sample has a fatigue limit of 414 M pa ,whereas non-ferrous materials, such as aluminium alloys are unlikely to suffer from such a phenomenon, but there is still no specific limit ascertained [1][2]. Figures 1 & 2 below present this information.

The actual stress range for materials like mild steel can be maintained below the endurance limit. Moreover, the design for specific number of stress variations can be developed if a certain portion of materials can be replaced at the stage of stress variation

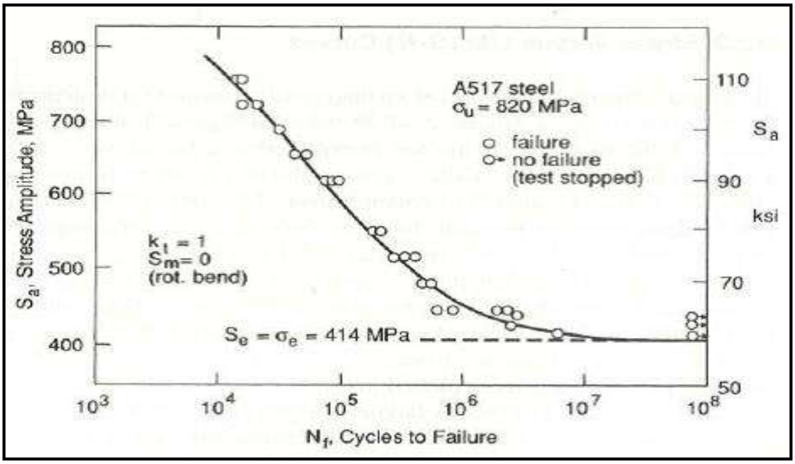


Figure 1: Stress-life time curve for ferrous material[3]

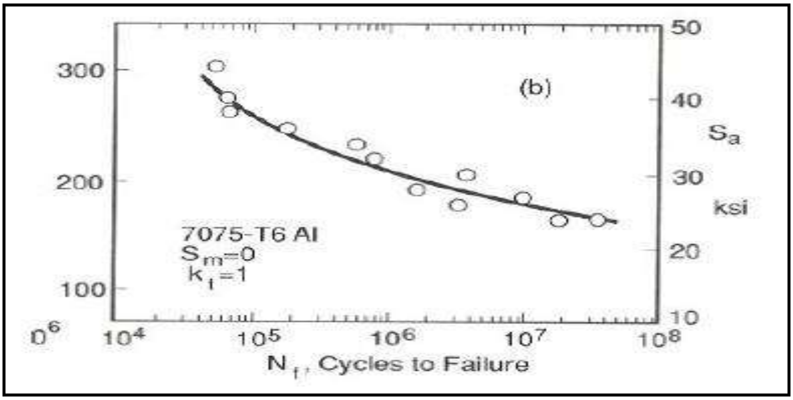


Figure 2: Stress lifetime curve for nonferrous material

The use of this method may be of benefit in aircraft construction as aluminum is commonly used in this construction. Results from the fatigue tests are important and are used by engineers to design parts to attain fatigue strength. Such results may, however, not be applicable, when designing for an infinite lifetime[4].

1.2- Fatigue Crack Growth (FCG):

The data gained from the Fatigue crack growth graph is important to explain the main force behind its be haviour. This data is commonly represented on a log plot of crack growth rate (da/dN) versus ΔK (stress intensity factor (ΔK=Kmax–Kmin)as shown in(figure 3).

The development of the analytical models is based on three different regions of the FCG curve, which denote the empirical data. The 'near threshold' region with a very slow crack growth is the region (I). In this region, the growth of a crack will not occur fast because the amount of driven force is below the threshold value. Although this region is highly influenced by the applied load it is also highly sensitive to the parts features and test environment such as material microstructure, grain size and operating temperature. Where as ,region (II) is an intermediate zone presented as a line relation on the crack growth curve. Region (III) is where the higher growth rate will occur leading to unbalanced final fracture. This occurs when the remaining cross-section of the tested material will not be able to carry the applied load although the maximum stress (Kmax)equals the fracture toughness of the material(Kc).[5]

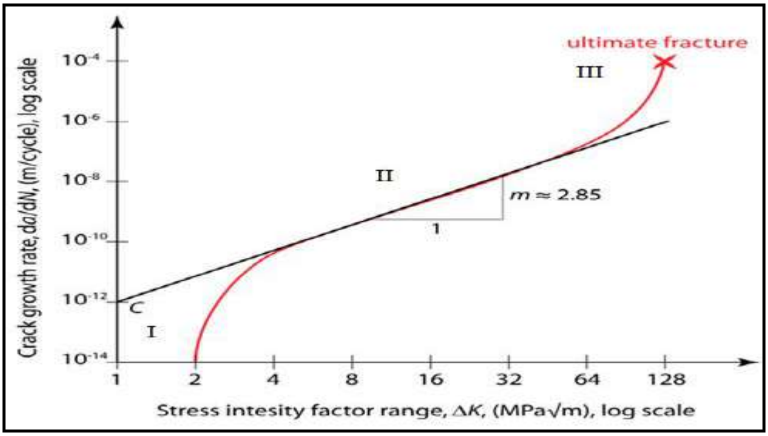


Figure 3: Typical Fatigue Crack Growth Curve Showing Three Regions.

All regions of the typical range of FCG data have been represented through various relationships, which have been developed over the years. To represent the linear region of the curve, the Paris Equation is the simplest relationship that was developed in 1963:

$$\frac{da}{dN} = C\,(\Delta K)^{n}$$

The applications used today are still applying this original model represented above, where the crack length is given by ‘a’, the empirical parameters are denoted by ‘C’ which is calculated from a curve fitting to test data, while ‘n’ stays in the range 3 to 5 for metals. The mean stress effects, threshold behaviour (region I), the instability asymptote (region III) and fatigue closure effects were studied based on this original model to develop more advanced versions of the Paris equation.[6][7]

For instance, For man and Walkers modified this relationship by introducing a factor dependent on (1-R).Where R = σmin/σmax or Kmin/Kmax, in the denominator to introduce flexibility for mean stress as linear model using the load ratio(R).

$$\frac{da}{dN} = C\left[\frac{\Delta K}{(1-R)^{1-m}}\right]^{n}$$

The empirical factors such as ‘C’, ‘n’ and ‘m’ are determined from the curve of FCG test data which was achieved at the various load ratios[8].

1.3- Surface Roughness Effect on Fatigue Life time :

Surface roughness parameters are describing all surface texture of parts in terms of various parameters. But the most commonly used parameter is the arithmetic average roughness (Ra), which is referred to the centre line average. Whereas (Rt) is the distance between the highest peak and the lowest valley in the same track [9].

Generally, fatigue behaviour has been proven to vary under different surface finishes for traditional material, but the knowledge for additive manufacturing is not fully studied because the process is changeable. For instance, surface carburization and scale defects are usually found on local forging metal which leads to decreased fatigue lifetime, specifically in high cycle fatigue region(HCF). However,the surface roughness of low cycle fatigue regions has less effect. On the other hand, the effect of the as-forged surface finish will be reduced through surface cleaning treatments such as, sand blasting. These techniques will remove scale defects with some of decarburized layers in orderto improve the surface properties. In some cases, compressive residual stresses can bemaintained at the top of surface, which it could be recommended especially for fatigue application.

The literature related to the effects of machined surface topography and integrity of fatigue lifetime was reviewed by Novovic et al. ,who found that the most commonly applied parameter was Ra,to describe the fatigue behaviour of material,but specimens with the same Ra value showed fatigue results with a typical 20% scatter. Thus ,R_t could be preferred in comparison to Ra, when determining the fatigue performance, as they successfully represented worst surface defects and allowed the initial crack growth[10].

In addition, a comparative study has been done by Spierings et al. ,to compare the behavior of conventional material and SLM (Selective Laser Melting) fabricated material under dynamic fatigue test. The results revealed that the fatigue lifetime for SLM SS316L samples is about 25%, less than that of the conventional materials at lower stress, even under differing surface conditions for the two tests. Also the endurance limit for SLM samples was demonstrated as 20% lower than conventional materials at lower stress. At higher stress(higher amplitudes) the materials showed a similar lifetime[11].

2- Description of the apparatus :

The induction squirrel cage motor was used to drive the fatigue tester HSM20 with a specific speed of 3000rpm. This is shown in the Figure 4. A 220V single phase power supply was provided. A counter mechanism is fitted at one side of the motor, which has the ability to record 7 figure members. A fixture is connected at itsend to the shaft. A spherical ball bearing is positioned in the loading device with a micro switch. When the fracture occurs, the motor is automatically switched off by the micro switch. The process was carried outwith the help of a fatigue tester, which is designed to be positioned on the bench. A standard specimen is provided for the apparatus. These specimenscomewith standard dimensions of (1x 10 x100) mm as demonstrated below.

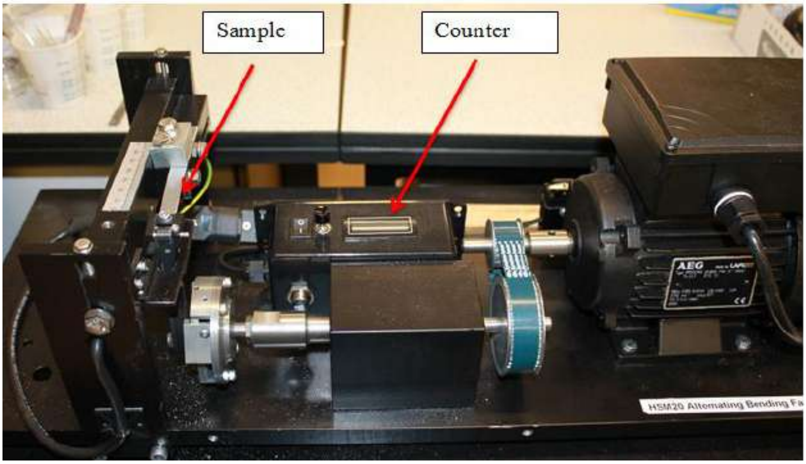


Figure 4: Fatigue tester HSM20.

3- Experimental Procedure:

SLM 125 was used to generate specimens in vertical orientation, through specific steps, start by CAD model (Sold Works)and turned to require end geometry with a specific dimension (100 x 10 x 1) mm. Thus,the manufacture parts have been completed.

The CAD model and the final manufacture parts (Figure 5& 6) are showed as the following:

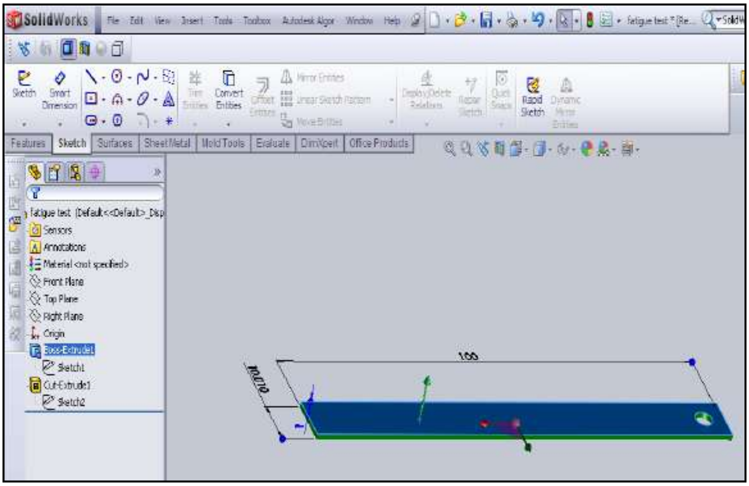


Figure 5: Shows CAD model part.

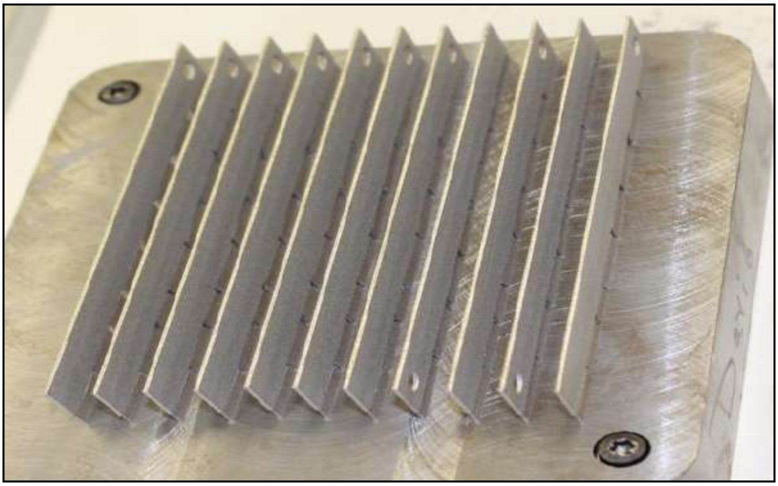


Figure 6: Shows the fatigue samples fabricated by SLM(125).

Twenty seven samples were manufactured and divided into three groups.Also surface roughness was measured for all three sets of SLM samples, as fabricated, Re-melted samples and Electro-polished samples, in order to detect the manner in which the fatigue lifetime is affected by the surface roughness.

The table below demonstrated details of the fabricated samples through different stages of surface improvement.

Table 1: Shows specimens' profile(1x 10 x100) with the most important parameters for surface finish improvement.

	Part	Process parameters &Comments
As fabricated		• Laser power 200 watt • Scan speed 480mm/s • Layer thickens 50 µm • Exposure time 100 µs • Average roughness (Ra) 9.15 µm ± 10%
Re –melted		• Grid scanning method • Laser power 180 watt • Scan speed 400 mm/min • Beam spot size 1mm • Hatch spacing 0.4mm • Focal distance 128 mm • Average roughness(Ra) 1.4 µm ± 20%
Polished		• Potential cell 4 volts • Ethylene 200 (ChCl:EG) as solution • Experimental time 45 min • Temperature 40 C° • Average roughness(Ra) 0.35 µm ± 15%

The experimental was carried out through three stages as :

1- Generate fatigue test on SLM samples(as fabricated material).
2- Generate fatigue test after Re-melted (as first stage to improve surface roughness).
3- Generate fatigue test after re-melted and polished (as final finishing stage).

The effects of the comparable rough surface quality on the specimen's lifetime were studied through this experiment. Cyclic cantilever bending was imposed on the samples at 1400 rpm, 20Hz when loading.

In order to clarify this process in a simple way, the processes of cyclic cantilever bending conditions were functional on the Y-axis to apply reversing stresses on each sample. Thus, the recorded results were taken for the total number of cycles to failure of each applied amplitude stress. Not all samples showed fatigue failure,especially those exposed to less than 500 M Pa of amplitude stress. Therefore,the test is usually terminated after about 2x105 cycles.

Then S-N relationship is ascertained for various specific loading amplitudes and created for the materials tested under varying stress amplitude. The stress amplitude is denoted by 'S', while the number of cycles are denoted by 'N'.

As the fatigue performance is severely affected by the amplitude of cyclic loading, the minimum peak stress divided by the maximum peak stress is the R ratio value, which is used to express the amplitude,as shown in the following figure.

- Stress ratio $R=\sigma min/\sigma max$.

It is most common to test at R ratio of -1 and kept constant.

- Stress range $\Delta\sigma = \sigma\ max - \sigma\ min$.
- The mean stress $\sigma_m = \frac{\sigma_{max}+\sigma_{min}}{2}$

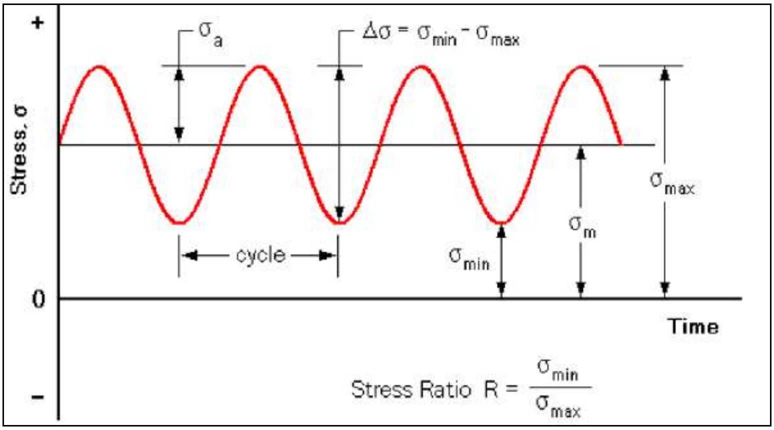


Figure 7 : Schematic of cyclic lodging.

The schematic of the fatigues test configuration is presented in the Figure 8 below.

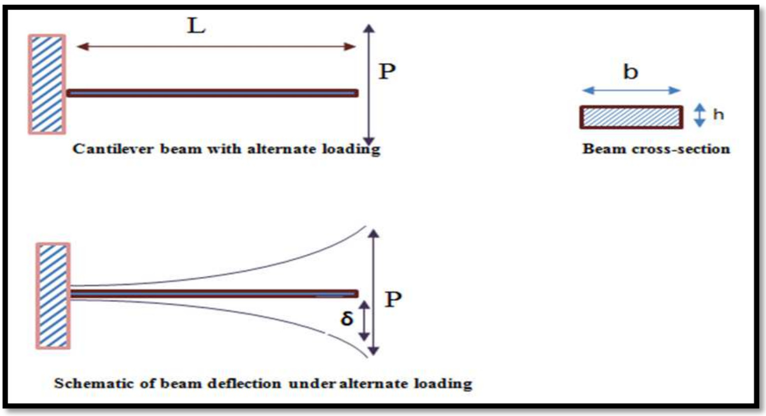


Figure 8: Schematic of the fatigue test configurations.

The following table presents the fixed conditions of tested samples;

Table 2: Specification of tested samples :

Specifications	Samples
The length of beam (L) = mm	40 mm
The width of Cross-section (b) = mm	10.1 mm
The height of cross section (h) = mm	1.02 mm
The second moment of area $I = \frac{b\,h^3}{12}$ =	0.9197mm4

The beams cantilever analysis is dependent on the followed equations;

A) Beam deflection $\delta = \frac{P\,L^3}{3EI} \quad (mm)$

Where δ is cantilever beam deflection, and E is Young's modulus (200) MPa and
P is the load preformed to generate specific deflection.

B) The maximum bending moment occurs at the fixed end is

M max = PL (Nm)

C)The maximum bending stress at the fixed end [12]

$$\sigma_{max} = \frac{M_{max} Y_{max}}{I} = \frac{M_{max} \left(\frac{h}{2}\right)}{I} = \frac{6PL}{bh^2} \text{(MPa)}$$

The first specimen was tested at high peak stress. This was a common procedure carried out at the point, where failure was expected in a short number of cycles.The test stress was reduced for each successive specimen by the reduction of cantilever deflection as shown in(Table 3). The failure result of each specimen was also recorded and repeated three times in order to determine the effect of surface quality of specimens subjected in two different stages of surface improvement and to compare the results as showed in (Table 4).

4- Results:

Table 3: shows beam cantilever data analysis.

No,S	L(mm)	h(mm)	b(mm)	I(mm)4	δ(mm)	P(N)	M max (Nm)
1	40	1.03	10.1	0.9197	9	77.599	3.10398
2	40	1.03	10.1	0.9197	8	68.978	2.75913
3	40	1.03	10.1	0.9197	7	60.356	2.41424
4	40	1.03	10.1	0.9197	6	51.733	2.06935
5	40	1.03	10.1	0.9197	5	43.111	1.72445
6	40	1.03	10.1	0.9197	4	34.489	1.37956
7	40	1.03	10.1	0.9197	3	25.866	1.03467
8	40	1.03	10.1	0.9197	2	17.244	0.68978

Table 4 :The average results of fatigue lifetime of specimens at various amplitude, subjected to varying surface finish techniques.

No of Samples	δ (mm)	σ max (MPa)	Fatigue lifetime (number of cycle)					
			As fabricated material		Re-melted material		Polished material	
			No of cycle	Error	No of cycle	Error	No of cycle	Error
1	9	1738.2	1618	110	2046	258	2272	319
2	8	1554	3302	231	4274	408	4843	556
3	7	1351.9	5476	175	7572	746	7733	781

4	6	1158.8	9623	387	11575	979	12706	877
5	5	965.6	19067	454	24913	2328	29009	3499
6	4	772.5	42028	1787	55738	4136	63601	5305
7	3	579.4	82229	3780	103503	7551	133627	10239
8	2	386.6	200000		200000		200000	

5- Discussion :

It is important to a expand the knowledge related to material properties of additive manufacture fields in order to broaden the field of component application. The dynamic mechanical be heavier (fatigue lifetime)of the SLM components have been surveyed through different three stages of surface qualities as shown in the followed (Figure 9).

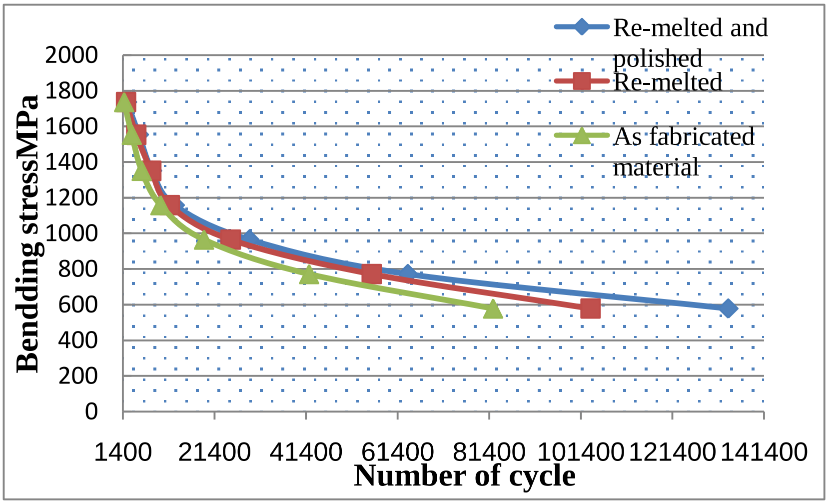


Figure 9: Stress-carve lifetime for tested material at different deflection.

The S-N relationship wasobtained for various specific loading amplitudes and created for the materials tested under varying stress amplitude. The stress amplitude is denoted by

‘S’, while the number of cycles are denoted by ‘N’.There were various drawbacks in the S-N fatigue data. Firstly, the actual service conditions of test specimens did not present the same conditions, but showed different scattering of fatigue life time. Although all the specimens have been made by the same parameters see (Table 1)and exposed to the same stages of surface finish improvement they showed different results from one sample to another. These differences leaded to an important change in the fatigue performance, generated as a result among the samples .The demonstrated results of fatigue test are highly sensitive to the a number of tested material .Moreover, it showed considerable amount of scatter in the fatigue lifetime data, especially at lower stress, whereas less scatter was recorded at high stress (see error in Table 4). This occurs in spite of the fact that the specimens were carefully made and treated.

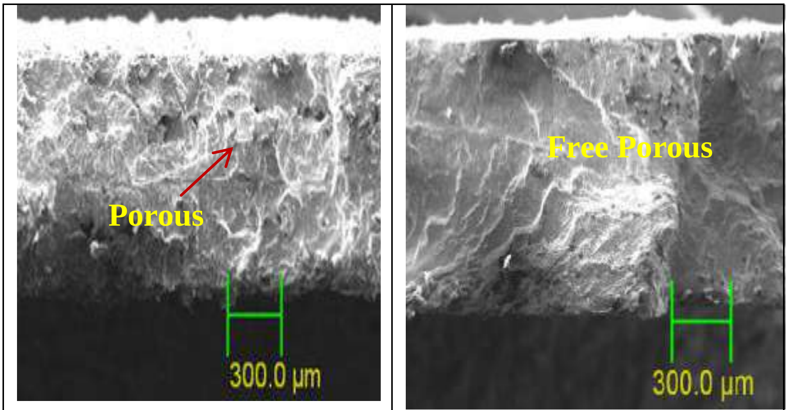
From the results observed in the above plotted(S-N) curve, the increase in fatigue lifetime is associated with decrease of the loading applied on the specimens. At higher stress, the lifetime is significantly lower for these materials even under different surface conditions, and it hasn't shown significant scattering for the three tests.

The re-melted samples with surface roughness (Ra)1.4 µm demonstrated significant fatigue lifetime particularly at lower stress and recorded about 30% improvement in comparison with those samples fabricated by SLM. In such case, it is possible to say that laser re-melting plays a significant role in improving the behavior of the fatigue lifetime of SLM components due to its ability to suppress any dendrite, pitting, porosity and residual stress could be initiated during the manufacture process. Also providing a homogenous surface with fine microstructure is important.[13].

For re-melted and polished specimens with surface roughness (Ra) 0.35µm±15%, the effect of surface quality ,failed to produce significant effects in the lifetime at higher amplitudes of stress, when compared to the behavior of re-melted material. This could be due to the high stress of applied load leading to a reduced crack growth period. However, an improvement in the fatigue lifetime has been recorded at lower stress. The results showed about 19%improvement comparable to previous re-melted samples. The reason behind this is the fatigue lifetime to failure depends on two periods, the crack initiation period and the crack growth period. In the case of polished surfaces, the crack nucleation on the metal surface is too small leading to an increase in the initiation period. Also the period of crack growth will be larger and covers the period of crack initiation.

5.1- Macroscopic characteristic:

The observations of fatigue failure of an SLM component can be initially observed by the naked eye and it is also advised to look at with small magnification. For instance, EG 2X 4X etc. This is in order to clarify details regarding to crack nucleation and surface damage during loading. The details of defects may be major in estimating the fatigue problem.



(A) As fabricated sample | (B) Re-melted sample

Figure 10: Micrograph of different fracture surfaces of different specimens at high stress 1350 MPa, for SLM part as fabricated (Ra= 10µm) and re-melted sample (1.5 µm)

Figure 10)shows fracture surfaces of specimens which have been obtained by SEM at low magnification. It was indicated that the fracture surface of specimens are different among the test due to the different of surfaces treatment condition. For specimens(Figure 10-A) with surface roughness (As fabricated and Ra=10µm) high number of defects on the surface(rough and porous) leads to raising stress at the loading point, which demonstrated the reason for fast failure. In such case, cracks can initiate at any points, where high stresses increase.

On the other hand, the possibility of cracks initiation are less than for re-melted and polished samples(Figure 10-B), surface roughness (Ra= 1.4µm& 0.35µm).This due to the surfaces being more flat and having reduced porosities, leading to decrease of stress raiser and surface roughness improvement.

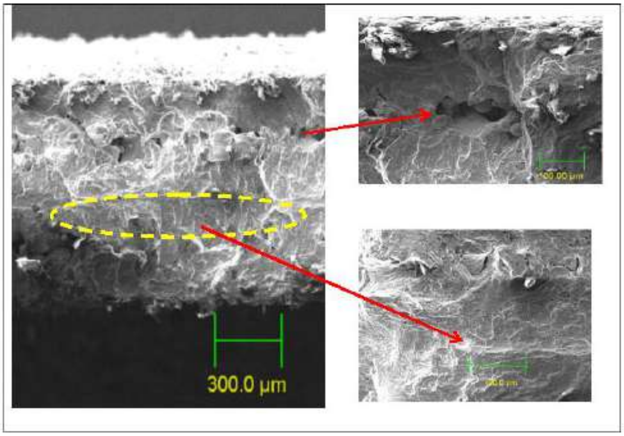


Figure 11 : Micrograph of fracture fatigue surfaces at high stress 1350 MPa for SLM part as fabricated (Ra= 10µm) to demonstrate different region of fatigue fracture surfaces.

Figure 11) shows that there are two regions in the fracture, as fabricated specimen. The first region is caused by the fatigue crack growth (out of circle in Figure 11)occurred in each cycle. As a result of the fatigue occurs by micro crack growth, a number of micro-cracks can be developed successfully on the surface and generate a large quantity of deformation. This could be enough to explain quick failure. The second region of fracture surface is that when the final cross section of specimen cannot longer carry the final applied load, leading to final fracture. In the case of SLM component, failures associated with fatigue and stress is commonly initiated by degradation on the surface, number of porosities and intensity of externally applied load. These problems can be reduced by laser re-melting leading to extending the lifetime of the material[14].

On the other hand, many conventional surface engineering techniques are available to solve this issue, and unlike the rest, laser re-melting is regarded as the most suitable method due to its flexibility to improve surface roughness, eliminate porosity, increasing fatigue and minimizing residual stress. This is the reason why cracks have never been easily initiated in a properly re-melted surface[15],[16].

Sun and co-authors has reported that improved wear and friction resistance of a stainless steel material surface has mostly been attributed to residual compressive stress and porosities removal from a material achieved through re-melting process .Furthermore, laser re-melting has been considered more effective in improving the material surface lifetime of stainless steel as well as to enhance corrosion and oxidation resistance[17],[18].

6- Conclusion :

The potential of surface finish which affects the fatigue life time of e surveyed samples showed various response. These variations are associated with different surface roughness due to the stages of improvement(both re-melting and polishing process).

The results of the study can be sum arised in the following points:

1. The change in amplitude is an influence on the variability in the fatigue lifetime of the samples.
2. The remaining defects (high surface roughness and porosity) associated with the manufactured 316L stainless steel made by SLM specimens, are a major factor affecting the fatigue lifetime.
3. Laser re-melting improves the fatigue lifetime of SLM stainless steel 316L about 30% at lower stress. The reasons behind that are the ability to supress surface roughness, porosity issues and reduce residual stress.
4. Electro-polishing after laser re-melting results in further improvement of fatigue lifetime and resulted about 19% at lower stress.

5. In both re-melted and polished samples failed to produce significant effects in the lifetime at higher amplitudes when compared to the behavior of as-fabricated samples.
6. The improvement of fatigue lifetime by laser re-melting and later Electro-polished can be attributed to the reduction of porosity issues, surface roughness and residual stress.

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Causes of Delays in Construction Projects in Many Developing Countries

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الخلاصة:

يعتبر التأخير في إنجاز مشاريع البناء في البلدان النامية من أكثر المشاكل شيوعاً والتي تواجه قطاع البناء والتشييد المحلي والدولي على حد سواء. وتؤثر المشاكل التي تؤدي إلى تأخير تنفيذ الأعمال في مشاريع البناء الدولية تأثيراً سلبياً على مختلف القطاعات الحيوية بما في ذلك اقتصاد تلك البلدان. إن الأسباب الرئيسية لتأخير مشاريع البناء قابلة للمقارنة فيما بين البلدان النامية. وبناء على ذلك تم الاستناد في هذه الدراسة على مسح استقصائي لدراسات سابقة، ومن ثم أُجريت مقارنة بين ستة بلدان نامية من مختلف دول العالم وتم دراسة حالة لدولة أخرى من أجل توضيح أسباب وآثار التأخير في مشاريع البناء والتشييد في العديد من البلدان النامية. وعلى الرغم من أن هناك العديد من الاسباب التي قد تقود إلى التأخير إلا أن نتائج هذه الدراسة أظهرت أن هناك عشرة أسباب رئيسية وتتمثل في: تغيير التصميم والمواد، الافتقار إلى إدارة الموقع، نقص الخبرة لدى المتعاقدين من الباطن، المشاكل المالية المتعلقة بالمقاولين، مشاكل التقديرات، تأخر المدفوعات من جانب المالك، ضعف عملية تخطيط المشاريع من قبل المقاول، تأخير وثائق التصميم، الافتقار لإدارة العقود من قبل الاستشاريين، وكذلك ضعف التنسيق بين الأطراف في الموقع. وعلاوة على ذلك تؤكد النتائج أيضاً أن هناك ستة آثار سلبية كبيرة ناتجة عن عملية التأخير، تتمثل في تجاوز الوقت، تجاوز التكاليف، النزاعات، التحكيم، التقاضي، والتخلي الكلي أو التام. وتختتم هذه الدراسة ببعض التوصيات لكل من المقاول والمالك بناءً على المشاكل والأسباب التي تم تناولها والتي تؤدي إلى التأخير في مشاريع البناء.

ABSTRACT:

Delays of construction projects in developing countries are one of the most common problems facing both local and international construction sector alike. Problems that lead to delays of works completion in international construction projects affect negatively on various vital sectors including the economy of those countries. The main causes of construction delays are comparable across developing countries. Consequently, this study is based on a literature survey, comparison conducted among six developing countries around the world and case study analysis in order to demonstrate causes and effects of delays in construction projects across many developing countries. Although, there are many causes may lead to delays, the results of this study showed that there are ten main causes including: change in design and material, lack of site management, lack of experienced subcontractors, financial problems contractor-related, problems of estimation, delay of payments by client, weakness of project planning process by contractor, delay of design documents, lack of contract management by consultant and poor coordination among the parties in site. Furthermore, the findings also confirm that there are six major negative effects of delay including time overrun, cost overrun, disputes, arbitration, litigation and total abandonment. This study concludes with some recommendations for both contractor and client in light of the problems and causes that have been addressed which lead to the delays in construction projects.

Keywords: Construction Projects, Developing Countries, Delay.

1. INTRODUCTION:

Most developing countries still suffer from the problem of delays in construction projects to date. There are many problems and causes that may lead to delays in construction projects in developing countries. Once the delay of works completion in construction project takes place, many negative effects appear successively. For instance, the project budget that has been allocated at the beginning will be overrun also the expected income that can be gained with the project facilities will be delayed [4]. Construction domain in developing countries is one of the most vital sectors that plays very significant role in economy [1]. All construction projects are restricted by scheduled contracts for many reasons including completion in time. Nevertheless, Delays in international projects in many developing countries are a common issue in particular in construction sector. The main objective of this study is illustrating the most common problems, causes and factors that cause delays in international construction projects in developing countries. Besides, the negative consequences of delays are also presented in this study.

2. LITERATURE REVIEW :

One of the first studies that concentrated to the causes of delays in construction projects has been conducted early in 1971 in USA by Baldwin and Manthei. 17 factors lead to the delays in construction projects in the US have been addressed in that study. After that in 1985 the other study conducted by Arditi et al. cited a number of causes that resulted delays in construction projects in Turkey. The causes involved difficulties of receiving payments from agencies, lack of materials, difficulties facing contractors and the organizational characteristics of contracting firms and public agencies. Nevertheless, related studies that have been published during the last two decades presented most causes, groups of factor and problems that lead to delays and its negative influences in construction projects in developing countries [8]. There are many research studies have been conducted to examine the issues that related to the causes of delays in construction projects especially in developing countries. Strategies that followed in most studies involved questionnaire approach and sometimes interviews in order to reach the real problems that cause delays in construction projects. Several studies found that most problems causing delays in various developing countries somewhat are similar. Nevertheless, most research studies that have been conducted across both developing and developed countries emphasise that there is a similarity among several problems causing delays in construction projects. These problems might include a complexity of construction and lack of professional human resources and design [8]. In this study, related literature has been reviewed to determine common causes of delay in construction projects in most developing countries.

2.1 Common Problems Causing Delays in Most Developing Countries:

This part of the study concentrates on the most common significant problems that may cause delays based on the relevant literature. As mentioned earlier that many problems of delays across different developing countries are somewhat identical. The following points represent the most of those problems that may lead to the delay according to several studies [8].

- Shortage of resources
- Lack of experienced subcontractors and nominated suppliers
- Poor management, particularly the contractual management
- Changing in orders
- Imperfections in regulation of public agencies
- Shortage of appropriate communication
- Delay of design
- Insufficiency of site planning and control
- Misjudgement in estimating resources
- Imperfections in project planning and scheduling [8].

Considering that the above points represent the common problems leading to the delays in construction projects in developing countries, the lack of resources is the first and most significant cause. No doubt that any construction project needs resources to begin including the most three important ones, finances, material and labour. This means that once there was a lack in resources, the project will suffer many issues from the initial phases. Nevertheless, each problem mentioned above plays very important role in the time extension of construction project along the stages of implementation. For instance, despite the problem such as changing of orders might be at the any phase of project, this change may cause delay as long as it is unexpected. The other significant problem is the poor contractual management. This problem may cause many negative results along the implementation phases of project because of mismanagement. Mismanagement might result in non-compliance with the terms of the contract and breach of its terms and therefore this will lead to delays.

2.2. Emergent Problems:

In addition to the above, according to several research studies that published in the first half of the past decade, there are some emergent problems that may cause delays in construction projects in developing countries [8]. These emergent issues can be included in the following points:

- Shortage of experience of contractor
- Slowness of decision-making process (client-related)
- Shortage of owner's experience
- Rise in prices of materials
- Shortage of labour's construction
- Complexity of Legal rules
- Lack of design criteria [8].

2.3. Groups of Factor :

There is a research study published in the last few years emphasises that there are seven groups of factor cause delays in construction projects. These groups of factor can be classified as the following [4].

- Financial factors.
- Managerial factors.
- Environmental factors.
- Project-based factors.
- Resource-based factors.
- Labour-based factors.
- Owner-based factors.

Each group include several problems and factors that could lead to the issues of delays, it is possible to address them one by one.

2.3.1. Financial Factors:

The financial factors are very important in such case of the delay. Cash flow problem is one of these factors and it can effect negatively on any construction project. The other significant factor is the financial problems of contractor, such factor sometimes lead to stopping the implementation of project. Furthermore, the delay of payments also causes much problems leading to time overruns in project. Besides, both fluctuation in prices of material and inflation are two important factors that may contribute to delays of works completion in construction projects [4].

2.3.2. Managerial Factors:

The managerial factors are very common in construction projects including disputes between the parties in site, conflicts related to the contract, change in design, loading a contractor excessive work, problem of estimation, shortage of contractor's experience, relations between manager and worker, poor coordination between the parties in site and lack of both quality control and site management [4].

2.3.3. Environmental Factors:

Environmental factors are very effective causes and can rapidly lead to many problems of delays. Environmental factors may represent a bad weather conditions, geological issues, location of the site and work-related injury [4].

2.3.4. Project-based Factors:

Factors related to the project might include shortage of feasibility studies, lack of modern construction methods and shortage of maintenance works as result to the lack of materials and equipment [4].

2.3.5 Resource-based Factors:

Most factors included in this group play effective role regarding the causes of delay. These factors might represent the issues related to the material storage, shortage of resource production, mismanagement of material, inappropriate selection of material and problems related resources transportation [4].

2.3.6. Labour-based Factors :

With respect to the labour-based factors group, there are three important factors. These factors could include lack of productivity of worker, lack of skilled labours and defects of construction. Each one of these factors can cause delay once it takes place during any phase of project [4].

2.3.7. Owner-based Factors:

In many developing countries, two major factors are under the responsibility of the owner. Both defects of management and owner's bureaucracy represent the two main causes of this group. These two causes can definitely contribute to delays in construction project [4].

3. COMPARISON AMONG SIX DEVELOPING COUNTRIES IN TERMS OF THE CAUSES OF DELAYS :

In this part of the study a simple comparison between six various developing countries around the world has been conducted in terms of causes of delays in construction projects. Based on the literatures [2], [3], [4], [6], [7] and [8] the comparison has been done according to the findings of those studies which published during the last decade between 2003 and 2010. Table 1 below demonstrates this comparison.

Table 1 Causes of delay based on comparison between 6 developing countries.

No.	Causes of delay in 6 different developing countries	Thailand 2008	Ghana 2003	Turkey 2010	Jordan 2008	Zambia 2009	Malaysia 2007	Rank
1	Change in design and material	√		√	√	√		2
2	Payments delay by client		√	√		√		3
3	Problems of cash flow		√	√		√	√	2
4	Financial problems contractor-related	√	√	√	√	√		1
5	Lack of productivity of worker	√		√				4
6	Problems of resources estimation	√	√	√	√		√	1
7	Defects of construction			√		√	√	3
8	Fluctuation in prices of material		√	√				4

9	Shortage of contractor's experience	√			√		√	3
10	Shortage of resource production						√	5
11	Mismanagement of material		√				√	4
12	Lack of site management	√	√		√		√	2
13	Inflation problems		√					5
14	Location of the site	√						5
15	Conflicts related to the contract	√				√		4
16	Lack of skilled labours	√		√	√	√	√	1
17	Shortage of feasibility studies		√	√	√			3
18	Bad weather conditions		√					5
19	Poor coordination among the parties in site				√	√	√	3
20	Lack of quality control	√			√	√		3
21	Defects of management				√			5
22	Problems related to resources transportation					√		5
23	Disputes among the parties in site						√	5

3.1. Discussion of the Comparison:

In this comparison it is possible to address a top ten of significant problems that cause delays in each country. After that, 10 out of 23 of the most frequent causes between these countries are addressed based on the higher points and ranking as shown below in chart 1.

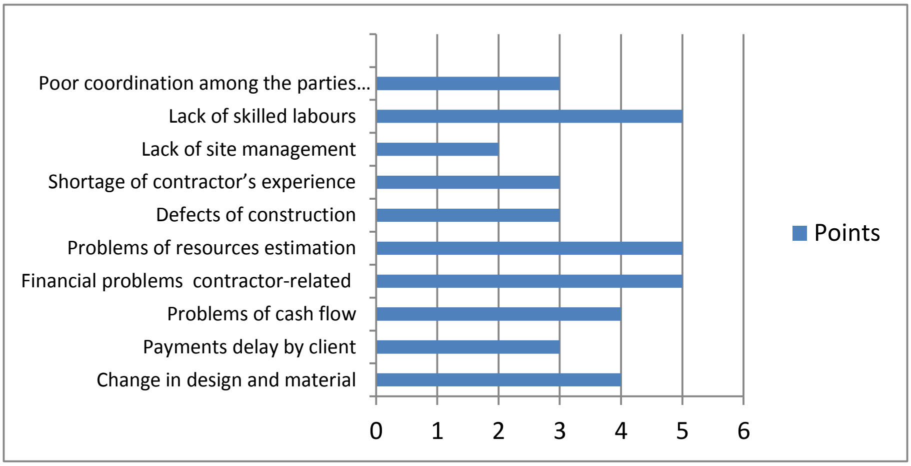

Chart 1 Top ten causes of delay based on higher points in table 1.

In light of this comparison, it seems that the first three points in the table below represent most frequent problems that may cause delay among those countries, the financial problems related to contractor, problems of resources estimation and lack of skilled labours. This indicates that the factors related to contractor, factors related to resources and factors related to labour are very important factors which may lead to the delay in those countries. Moreover, the next three ones are also important factors causing delay which include changing in design and material, problems of cash flow and lack of site management. Besides, as can be seen in table 2 above, the last four problems in the top ten represent the delay of payments by client, some defects of construction, lack of contractor's experience and lack of feasibility studies. By taking into consideration the factor groups that presented earlier, the above ten causes of delay are included in four of those groups. Financial factors, managerial factors, labour-based factors and project-based factors. In general, this does not mean that the other remaining problems are neglected in this comparison. This eventually depends on the situation of each country.

Table 2 Top ten causes of delay based on comparison between 6 developing countries.

No.	Top 10 causes of delay in construction projects in 6 developing countries	Rank
1	Financial problems contractor-related	1
2	Problems of resources estimation	1
3	Lack of skilled labours	1
4	Change in design and material	2
5	Problems of cash flow	2
6	Lack of site management	2
7	Delay of payments by client	3
8	Defects of construction	3
9	Shortage of contractor's experience	3
10	Poor coordination among the parties in site	3

4. CONSEQUENSES OF DELAYS :

There is no doubt that the delays in construction projects have immense influence on the project itself. Most research studies that concentrated on causes of delay and its impacts in construction projects indicate to that the impacts could be similar across most developing countries. Although the problems that may lead to the time overruns in the projects sometimes vary from country to country, the effects of delay are almost identical across those countries. Based on the literature [6] there are six major negative effects of delays have been addressed in this study.

4.1. Time Overrun :

One of the most common consequences of delays is a time overrun. Delays in any project may cause time overrun however, what are causes of these delays. There are some studies emphasis that the factors related to both contractor and client can affect on the time overrun. Factors related contractor such as shortage of contractor's experience, inadequate planning and lack of site management by contractor. The other thing is that the delay of payments that must be paid for the completed works may impact too. Besides, there are some other studies indicate that the labour-based factor and consultant-related factors can lead to time overrun, while some studies say that the consultant-related and material-related factors may cause time overrun [6]. Consequently, this leads to say that the factors that may cause time overrun are the same factors that can lead to the delays.

4.2. Cost Overrun:

Cost overrun in construction projects could be caused by contract related factors. These factors might represent change orders, mistakes in the document of contract such as mistakes in payment terms and duration of project. In any case, the problems that cause delays can lead to time overrun then naturally time overrun will cause in cost overrun [6].

4.3. Disputes:

There are several factors and causes of delays that may lead to disputes during project duration. For instance, owner's based-factors, contract-related and delay in the payments for completed work. Furthermore, frequent client interference, shortage of communication among the different parties, and changing in orders may increase opportunity of disputes between the different parties [6].

4.4. Arbitration:

In most cases the disputes among the parties become in need to arbitration process in order to be settled. These disputes occur normally as result to delay's factors of both owner and contract relationship. A competent third-party can settle the disputes instead going to the court [6].

4.5. Litigation:

Once the disputes become hard to settled, the litigation process is the appropriate option. The factors that may reach the litigation process include labour-based factors, contract relationship-based factors, contract-based factors and client-based factors. In general, litigation process is considered as a last resort to settle disputes between parties [6].

4.6. Total Abandonment:

Total abandonment normally occurs gradually in the absence of all possible ways of settling including the litigation process. Factors of delays that may lead to the total abandonment include labour-based factors, contract-based factors, consultant-based factors and owner-based factors [6].

5. CASE STUDY:

5.1. Significant Factors Causing and Effects of Delay in Iranian Construction Projects:

This case study has been addressed in order to link between its Findings and what has been presented in the study in terms of the causes and effects of delays in construction projects. This case study has been conducted last year to determine both causes and negative effects of delay in construction projects in Iran. This study concentrated on projects of roads and administration buildings using a questionnaire survey to find the causes and impacts of delay from 100 viewpoints of both consultants and contractors. By using the statistical procedures and recommendations, the data analysis has been discussed to minimise delay in construction projects. The related literature that reviewed in this study was published over the last decade [5].

5.2. Causes of Delay in Construction Projects in Iran:

In this study, ten important causes of delays in construction projects in Iran have been specified according to the analysis of the results. These causes can be seen in the table 3 below. The results demonstrated that there are three causes in high ranking among the top ten. The lack of site management, delay of payments by client and changing in design and material are in the first three ranks respectively [5].

Table 3 Top 10 causes of delays related to contractor and consultant viewpoints [5].

No.	Causes of delays in construction projects in Iran	Contractor Rank	Consultant Rank	Overall Rank
1	Lack of site management	1	1	1
2	Delay of payments by client	2	7	2
3	Change in design and material	3	5	3
4	Weakness of project planning process by contractor	7	2	4
5	Financial problems contractor-related	6	3	5
6	Slowness of decision-making process client-related	5	6	6

7	Delay of design documents	4	10	7
8	Delay of reviewing design documents client-related	8	4	7
9	Lack of contract management by consultant	5	12	8
10	Subcontractors problems	10	6	9

5. 3. Effects of Delay in Iranian Construction Projects:

The delay in construction projects can lead to many negative effects. In this case study, six impacts of delay have been observed according to the viewpoints of contactor and consultant. These effects include time overrun, cost overrun, disputes, arbitration, total abandonment and litigation. The consequences of delays in construction projects can be shown in table 4 below.

Table 4 Consequences of causes of delay in construction projects in Iran [5].

No.	Consequences of the delay	Contractor	Consultant	Overall
		Rank	Rank	Rank
1	Time overrun	2	1	1
2	Cost overrun	1	2	2
3	Disputes	3	3	3
4	Arbitration	4	4	4
5	Litigation	6	6	6
6	Total abandonment	4	5	5

6. DISCUSSION OF THE FINDINGS :

Considering that causes of delays in construction projects are based on the results of the comparison taking into account the findings of the case study and what shown in the study according to the previous studies. By comparison, there is identically by around a half between the top ten causes of delays in construction projects in case study and the top ten causes that observed from the comparison conducted in this study. The similarity includes lack of site management, delay of payments by client, financial problems contractor-related and change in design and material. In addition, again there is a similarity between the result of the comparison and the most common ten causes of delay that presented based on the literature survey. For instance, lack of experienced subcontractors and nominated suppliers, poor of management, changing in orders, poor coordination among the parties in site and misjudgement in estimating resources. This means that there is a huge similarity between the causes of delays in construction projects across most developing countries. On the other hand, with respect to the consequences of the delays, once again there is identical between the negative impacts of delays in case study and the negative influences of delays in different developing countries that mentioned earlier in this study. The six observed effects of delays are the same. It is clear that there is a great matching among the result of case study and what presented in this study including the results of comparison. This leads to believe that the following ten problems can effectively cause delays across many developing countries.

1. Change in design and material.
2. Lack of site management.
3. Lack of experienced subcontractors.
4. Financial problems contractor-related.
5. Problems of estimation.
6. Delay of payments by client.
7. Weakness of project planning process by contractor.
8. Delay of design documents.
9. Lack of contract management by consultant.
10. Poor coordination among the parties in site.

It can be noted that many causes of delays are related to contractor, client and subcontractor. For instance, the financial problems related both contractor and client. Once the contractor or client starts suffer from the financial issues, this means that the symptoms of delays will appear soon. Besides, once the subcontractor suffers from the lack of experience, this also strong indication that the construction project probably will pass a several difficulties. Nevertheless, the consultant also can play role in delays in different stages of project, for example, once the consultant does not give sufficient attention to the management of contract, the delay probably takes place.

7. CONCLUSION:

In this study, causes and consequences that lead to delays in construction projects in developing countries have been investigated. This investigation has been conducted based on the literature related and previous research studies. In addition, comparison has conducted between six developing countries in this study. Furthermore, analysis of case study that links results of the comparison and what presented in the study. The results show that there is a similarity in causes and identical in effects of delays in construction projects in most developing countries. Based on what mentioned above, this study concludes that the most common causes of delays have been grouped in ten factors, change in design and material, lack of site management, lack of experienced subcontractors, financial problems contractor-related, problems of estimation, delay of payments by client, weakness of project planning process by contractor, delay of design documents, lack of contract management by consultant and poor coordination among the parties in site. Besides, the impacts of delays as the findings demonstrated are six, time overrun, cost overrun, disputes, arbitration, litigation and total abandonment.

8. RECOMMENDATIONS :

The recommendations that could be provided in this study in terms of the causes of delays in construction projects in developing countries are as follows:

- Recommendations to clients:

1. Clients should follow right ways during selection process of contractors by applying selection criteria.
2. Client should not have delays in payments for a completed works to the contractor.
3. Client must avoid major changing in order and requirements.
4. Client should not interfere frequently during the execution period.

- Recommendations to contractors:

1. Contractors should have sufficient experience regarding the international construction.
2. Contractors must give more concentration to site management by depending on a good experience of site-managers.

3. Contractors should ensure that they have sufficient financial support and manpower.
4. Contractor must make sure apply selection criteria during selection process of subcontractors.

It is also recommended that local studies should be carried out for some developing countries that lack such studies, in order to determine whether they suffer from the same causes of delays or there are additional factors. As well as to investigate in some further aspects such as the type and classification of projects whether public or private are they related to the delay or not. In general, by conducting much studies and comparisons between several developing countries it can specify more accurate causes of delays. Consequently, such studies may assist the international construction sector to avoid many negative impacts in future. Furthermore, developing countries can also take advantage of these studies to improve their economical situation with respect to the international construction.

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