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Effect of Die Geometry on Thermal Fatigue Analysis of Aluminium Alloy (A02240) Using Pressure Die Casting Process

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ABSTRACT

Dies for aluminium alloys die-casting fail because of a great number of different and simultaneously operating factors. Some of them may be controlled to some extent by the die-casting experts. In the process of the die-casting the primary source of loading is cyclic variation of the temperature; the influence of other loads is relatively insignificant. For economical production of aluminium and aluminium alloys die castings it is important that the dies have a long working life. The replacement of a die is expensive in both: money and production time. The die design, the material selection and the process thermal fatigue stress which is the consequence of the working conditions, the inhomogeneous and to low initial temperature of the die, contribute to the cracks formation. The main objective of this work to find out The thermal fatigue of die casting saffil-reinforced aluminium alloy (96%Al_2O_3/4%SiO_2) causes reduction in tool life and seriously affects the surface conditions such as microstructure, hardness, surface finish and residual stresses. The size and location of cooling channels relative to the surface of the die, which affect the thermal stresses and fatigue life of dies. This work focus on thermal fatigue analysis of Aluminium alloy pressure die casting process and analyses the effect of coolant channel location on temperature distribution and fatigue parameters such as life, damage, equivalent alternating stress and biaxiality using ANSYS Workbench 17.1 finite-element package.

Keywords: Aluminium alloys, Die-casting, Thermal fatigue, Temperature distribution, life

I. INTRODUCTION

Die casting is a very cost-efficient method of forming thin walled and complex near net-shaped products with geometric tolerances and good surface finish. Low melting point alloys based on aluminium, zinc, magnesium and copper are frequently used. Many different types of products are manufactured by die casting such as engine blocks, cylinder head covers, valves, Pipe coupling etc. and other components for the automotive industry and for heating etc. In die casting, large numbers of identical products are produced using one die, which is necessary, since the die is very expensive. Any kind of tool failure that causes rejection of casting and extra tool maintenance increases the production costs. The overall aim of this work to development of better tool materials for die casting. Die Casting tools are exposed to thermal mechanical and chemical conditions during each casting cycle. The service life of tools for aluminium die casting is most important thermal fatigue cracking, erosion, corrosion of the casting alloy to the tool. Thermal fatigue cracking in die casting of aluminium alloy, since the temperature of the melt is high.

1.1 Die casting: Die casting process is that the liquid metal is forced by the application of pressure to flow with high velocity during injection and completely and rapidly fill an internally cooled mould, typically within the order of milliseconds. The high melt velocity during injection and the continuous internal cooling of the tool during the process allows production of thin-walled net-shaped cast products at high manufacturing rates. The complexity of the castings and the manufacturing rate are considerably beyond those provided by the permanent mould (gravity) casting process.

There are two principal types of die casting machines, either classified as hot chamber or cold chamber machines. In the hot chamber machine process, the liquid metal injection mechanism is submerged in the molten metal, and the cylinder is automatically filled with metal prior to each casting operation when the injection plunger rod is withdrawn. This process is typically applied for low melting point casting alloys, which cause the minimum of attack on the injection system material during the contact with the liquid metal. In the cold chamber machine process, the injection mechanism is separated from the molten metal, and the cylinder is filled with metal prior to each casting operation using a ladle. The cold chamber process minimises the liquid metal exposure of the injection system components, and it is normally applied for casting alloys with higher melting points, e.g. aluminium alloys.

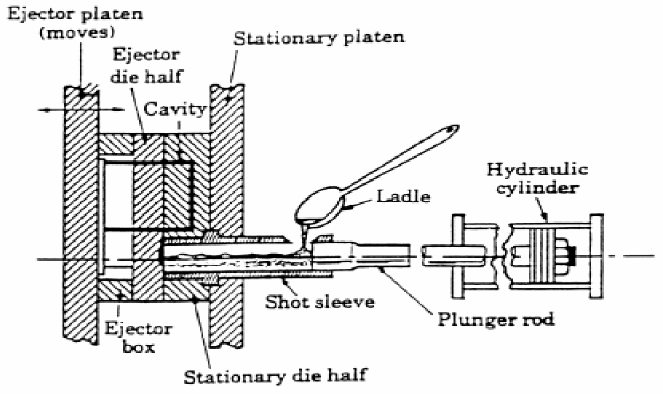

Fig.1.1: Cold-chamber die casting

1.2 Die-Casting failure mechanism: Aluminium alloys castings which are produced all through the world by the use of gravitational die casting or high pressure die casting is used in different automotive parts and consumer goods. One of the major concerns in die casting is the durability of die materials/surface when they are exposed to pressurised casting process during filling, high temperature molten aluminium flow, and solidification and die holding stages. In die casting process, the molten aluminium alloy is injected into die cavity at high speed of 30-100 m/s at temperatures between 670 – 710 ^{0}C and injection pressure of 50-80 MPa. Several failure modes appear on aluminium die casting surface such as soldering effects, washout gross-cracking and thermal fatigue cracking which happen in effect of heat checking. Die-casting dies are high mechanical and thermal loads. Thermal fatigue cracking of dies which is caused by thermal cycling might considerably reduce the die lifetime. Cracks reduce the surface quality of dies and consequently the surface of castings will decline. During the process cracks are identified and their size and location are measured. Thermal and mechanical loads produce high local stresses which make the surface to crack.

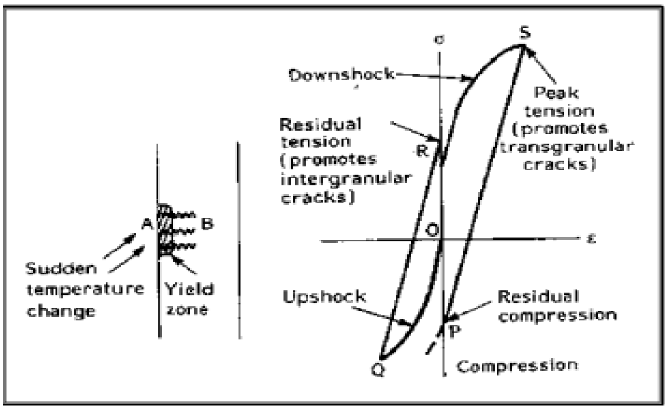

Fig.1.2: Hysteresis loop at the surface of a material subjected to cyclic heating cooling

1.3 Thermal Fatigue in Die-Casting: The thermal fatigue resistance of aluminium alloy can be studied through high-pressure die-casting process. The thermo-mechanical fatigue causes heat checks on the surface. The mechanical properties of the material grow instable in result of heating the die material. The thermal stresses, which take place in the die, develop from the thermal gradient across the die area. The thermal gradient is made in the result of the heating and cooling of the surface during the injecting stages of the casting cycle. With an increase in the temperature, the yield strength of the material is lowered and the compressive strains might grow plastic. The surface temperature decline quickly once a flow of heat is conducted to the lower layers. When the casting is ejected, cooling the surrounding from the surface help to decrease the surface temperature. If the surface cools more than the interior, the compressive strain are released and tensile strains might be produced.

1.4 Thermal Stress in Dies-Casting: The thermal stresses, which take place in the die, develop from the thermal gradient across the die area. The thermal gradient is made of the heating and cooling of the surface during the ejecting, injecting stages of the casting cycle. When the molten aluminium is injected into the die, the die surface heats up as opposed to the cooler mass of the die. With an increase in the temperature, the yield strength of the material is lowered, and the compressive strains might grow plastic. When the casting is ejected, cooling the surroundings from the surface, and further decrease the surface temperature.

II. Material Properties

In our investigation work a complex analysis of a typical dies for die-casting of Saffil-reinforced aluminium alloy ($96\%Al_2O_3/4\%SiO_2$) has been carried out. The material used in the object is high pressure die casting of aluminium alloys. The physical properties of saffil-reinforced aluminium alloy ($96\%Al_2O_3/4\%SiO_2$) which is shown below as table 2.1

Table 2.1: Properties of Saffil-reinforced aluminium alloy ($96\%Al_2O_3/4\%SiO_2$)

Density(g/cm^3)	3.5×10^{-9}
Tensile Strength(MPa)	1800
Modules of Elasticity (GPa)	330
Latent Heat of Fusion(kJ/kg)	1070
Specific Heat(J/kg.K)	1000
Thermal Conductivity(W/m.K)	25.6
Shear Modulus(GPa)	125
Poisson's Ratio(ν)	0.27

III. Transient Thermal and Structural Analysis

3.1 Geometric modelling of die-casting: The discretization of the geometric model was carried out using ANSYS workbench 17.1 was discretize the CAD model with quadratic displacement behaviour is exhibited by the elements.

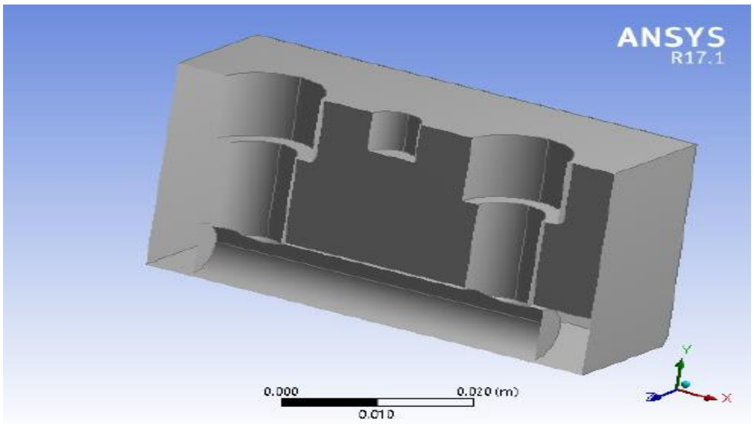

Fig.3.1: Geometrical 3D CAD model

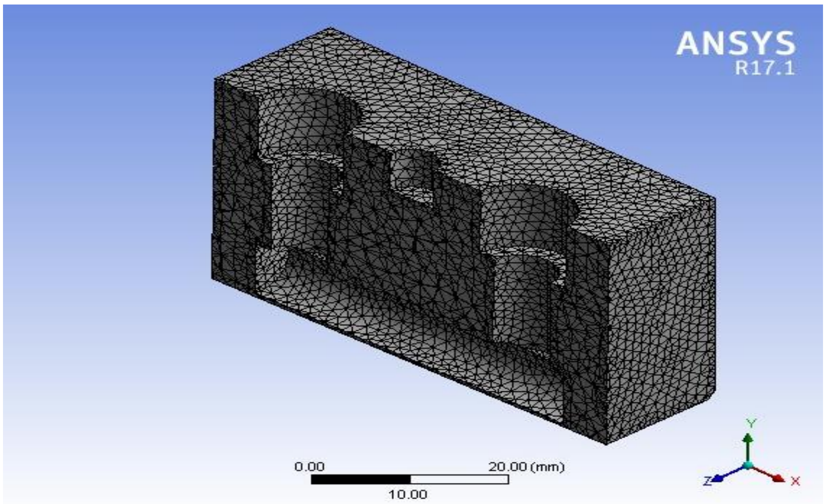

Fig.3.2: Messing of Die Geometry

3.2 Thermal Analysis of Saffil-reinforced aluminium alloy (96%Al_2O_3/4%SiO_2) Die Casting:

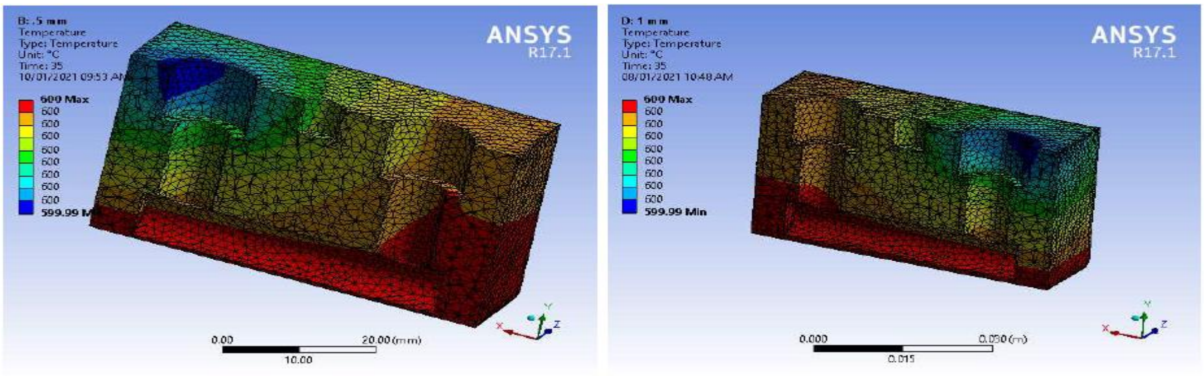

Fig. 3.3 (a) Temperature Distribution for 0.5 mm base location **(b)** Temperature Distribution for 1 mm base location

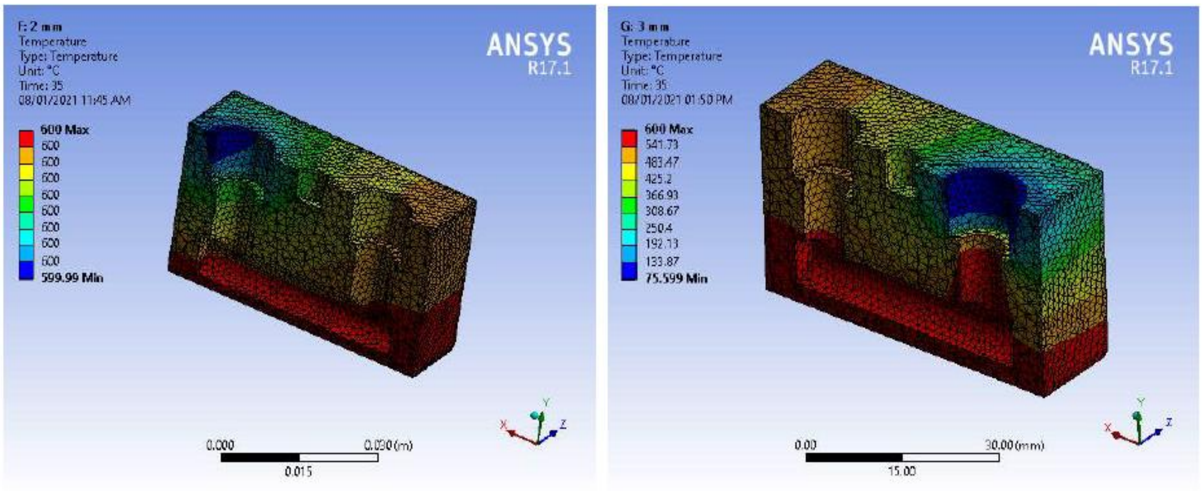

Fig.3.4 (a) Temperature Distribution for 2 mm base location **(b)** Temperature Distribution for 3 mm base location

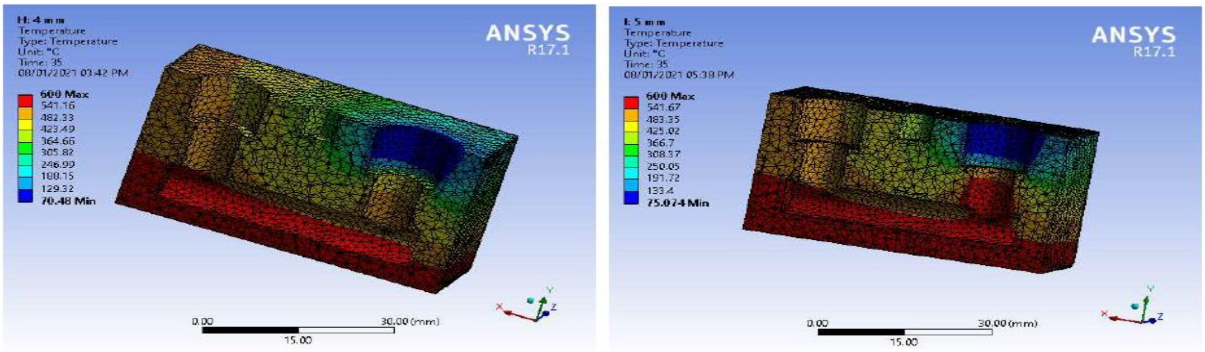

Fig. 3.5:(a) Temperature Distribution for 4 mm base location **(b)** Temperature Distribution for 5 mm base location

3.3 Fatigue Analysis (Life) of Saffil-reinforced aluminium alloy (96%Al_2O_3/4%SiO_2) Die Casting:

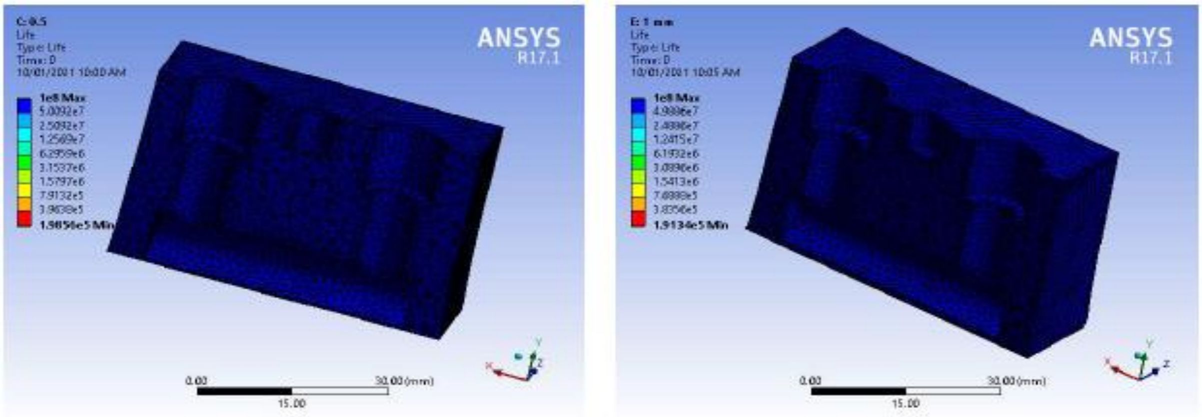

Fig. 3.6: (a) Fatigue Life for 0.5 mm base location **(b)** Fatigue Life for 1 mm base location

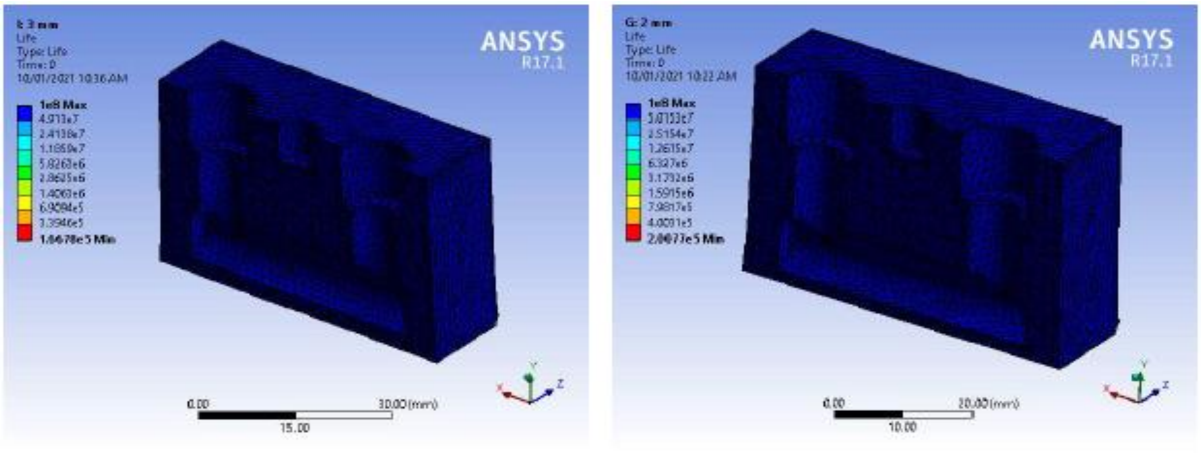

Fig. 3.7: (a) Fatigue Life for 2 mm base location **(b)** Fatigue Life for 3 mm base location

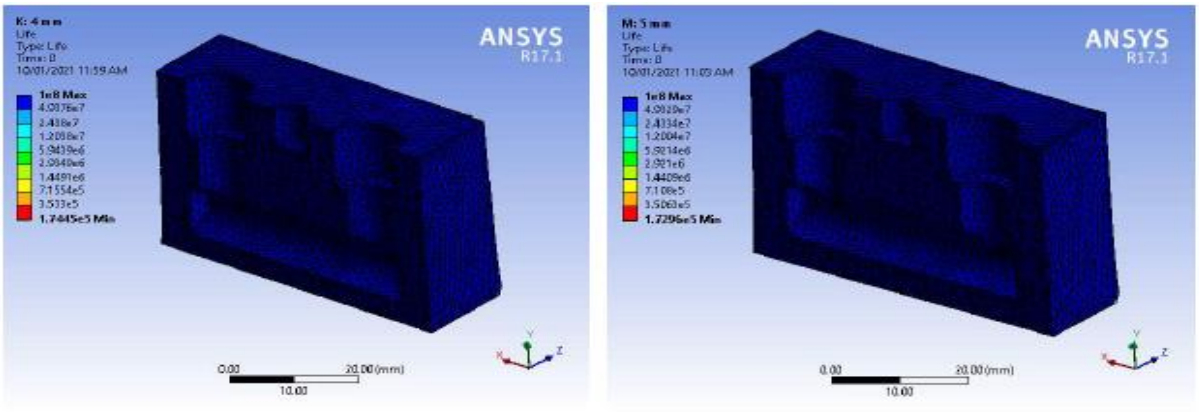

Fig. 3.8: (a) Fatigue Life for 4 mm base location **(b)** Fatigue Life for 5 mm base location

Table 3.1 Results of thermal fatigue simulation test for Saffil-reinforced aluminium alloy (96%Al_2O_3/4%SiO_2) Die Casting

Sr. No.	Coolant channel location (mm)	Temperature (⁰C)	Normal Stress (MPa)	Fatigue Life(cycles)	Fatigue Damage	Equivalent Alternating stress(MPa)	BiaxialityIndication
1	0.5	599.99	207.64	198560	5036.4	165.48	0.98636
2	1	599.99	208.95	191340	5226.2	166.22	0.98741
3	2	599.99	207.81	200770	4980.9	165.26	0.99656
4	3	75.99	211.07	166780	5996	168.94	0.997
5	4	70.48	210.75	174450	5732.3	168.05	0.99012
6	5	75.074	211.71	172960	5781.5	168.21	0.99435

IV. Results and discussions

4.1 Effect of coolant channel position on temperature distribution: Figure 3.3(b) illustrates the temperature distribution of aluminium alloy (A02240) for the coolant channel location situated at 1 mm from the base and Figure 3.3(a) illustrates temperature distribution for varying coolant channel locations. The coolant channel location situated at 0.5 mm from the base experienced a temperature of 599.99 ^{0}C, whereas other positions at 1,2,3,4 and 5 mm from the base experienced 599.99, 599.99, 75.99, 70.48 and 75.074 ^{0}C, respectively. The minimum temperature of the die that has to be maintained to reduce the thermal crack and the average tool temperature is usually kept at determined levels through internal cooling. Cooling channel close to the bottom surface increases the heat transfer rate through forced convection, resulting in less thermal expansion. From this, it is expected that the thermal fatigue cracks will appear at the specimen surface due to higher temperature and due to the decreased strength at elevated temperature. As the coolant channel location distance from the base increases, the surface temperature varying with channel location distance from the base for saffil-reinforced aluminium alloy. Hence, it leads to expectation of crack initiation at higher distance from the coolant channel location.

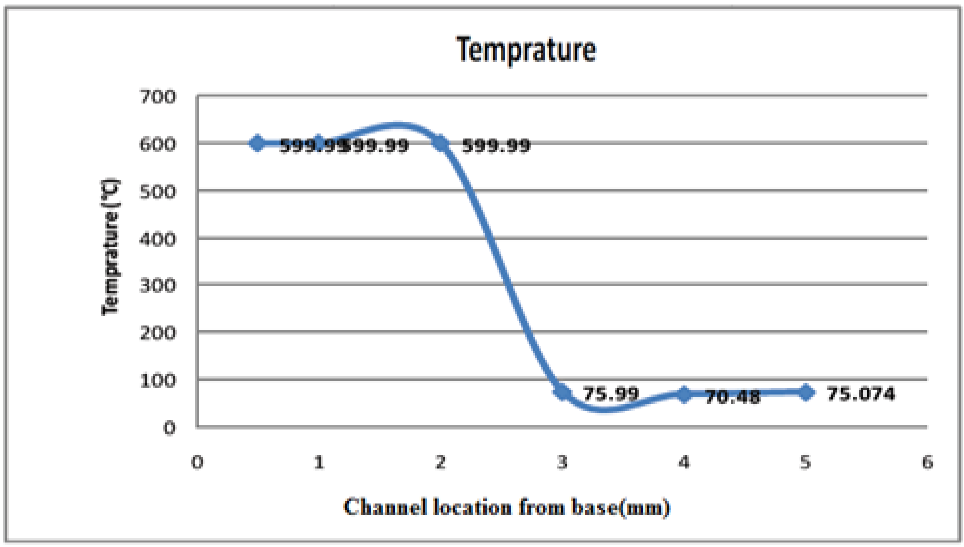

Fig. 3.9: Temperature distribution for Saffil-reinforced aluminium alloy

4.2 Effect of coolant channel location on die fatigue life: Geometry plays an important role in the stresses produced during thermal fatigue loading. Table 3.1 shows the results of coolant channel location on die fatigue life for saffil-reinforced aluminium alloy (96%Al_2O_3/4%SiO_2). The coolant channel location situated at 1 mm from the base experiences increase in fatigue life due to cooling channel nearer to the base; it experiences a minimum normal stress 207.64 MPa for Saffil-reinforced aluminium alloy (96%Al_2O_3/4%SiO_2) due to thermal expansion. As the wall thickness of the die increases, the normal stresses increasing. Also the die life drastically decreases. This may be explained by the fact that die casting of thin-walled specimen encounters high turbulent flow of molten material, which will induce volume porosity; this in turn decreases the die life. The fatigue life plot for 1 mm from base is as shown in figure 3.10(b) for Saffil-reinforced aluminium alloy (96%Al_2O_3/4%SiO_2).

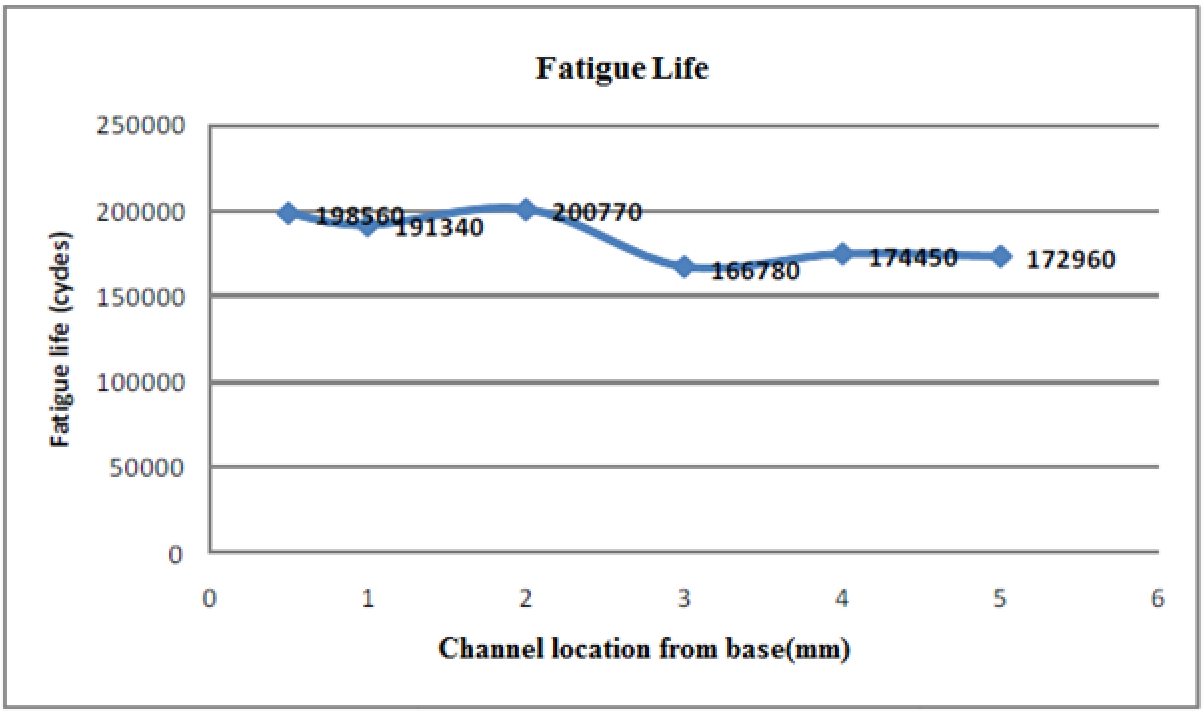

Fig. 3.10: Fatigue life for saffil-reinforced aluminium alloy

4.3 Effect of coolant channel position on fatigue damage: Fatigue damage is a contour plot of the fatigue damage at a given design life. Fatigue damage is defined as the design life divided by the available life. The coolant channel location 1 mm from the base, as shown in figure experiences less fatigue damage of about 4980.9 for Saffil-reinforced aluminium alloy (96%Al_2O_3/4%SiO_2) as compared with the farther coolant channel locations. The thermal fatigue damage is a function of thermal gradient and thermal expansion coefficient of the material. According to Abdulhadi et al, compression stresses developed exceed the elastic limit of the die material only if the integration of the temperature gradient and the widespread thermal expansion is high enough. In the present case, when the coolant channel position is increased from 0.5 to 1 mm there is no considerable change in temperature distribution and hence thermal gradient does not contribute for increase in fatigue damage. Hence the fatigue damage decreased from increase in coolant position.

4.4 Effect of coolant channel position on equivalent alternating stress: In a stress-fatigue life analysis, one always needs to query for an S-N curve to relate the fatigue life to the stress state. Thus the "equivalent alternating stress" is the stress used to query for the fatigue S-N curve after accounting for fatigue loading type, mean stress effects, multiaxial effects and any other factors in the fatigue analysis. Thus, in a fatigue analysis, the equivalent alternating stress can be thought of as the last calculated quantity before determining the fatigue life. The coolant channel location 1 mm from the base has less equivalent alternating stress of about 166.22 MPa for Saffil-reinforced aluminium alloy (96%Al_2O_3/4%SiO_2) as shown in figure Hence increase in coolant channel location from the base with varying the stresses.

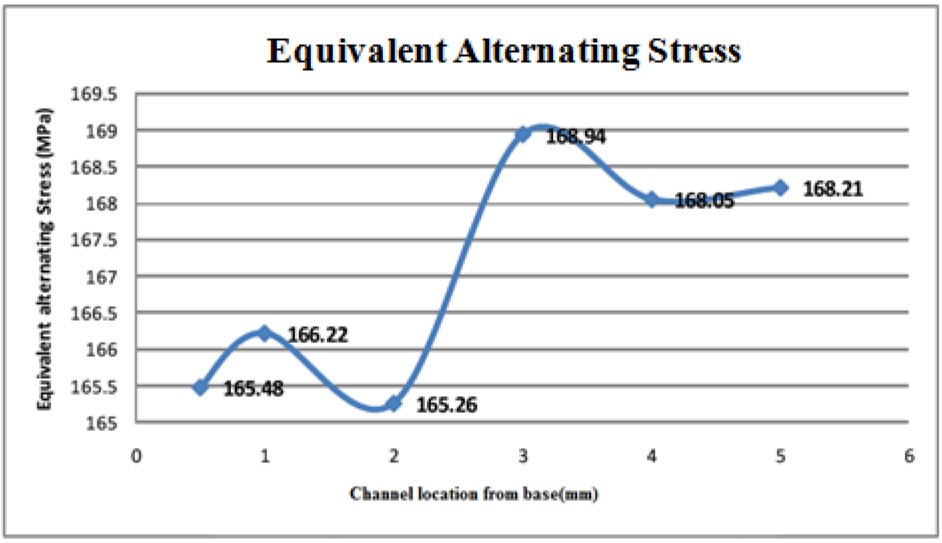

Fig. 3.11: Equivalent alternating stress for saffil-reinforced aluminium alloy

4.5 Effect of coolant channel position on biaxiality indication: Biaxiality indication is defined as the principal stress smaller in magnitude divided by the larger principal stress with the principal stress nearest zero ignored. A biaxiality of zero corresponds to uniaxial stress, a value of -1 corresponds to pure shear and a value of 1 corresponds to a pure biaxial state. Variation of coolant channel locations for the biaxiality plot indicates that the model approaches towards biaxiality stress state. A summary of thermal fatigue simulation results obtained is presented in table 3.1.

V. CONCLUSION

The life of high-pressure die casting could be increased by using an effective cooling channel near the base and greater thermal stable of mechanical properties at operational temperature. Thermal fatigue analysis was carried out using Workbench 17.1 package in order to characterize mainly included temperature distribution, normal stress and fatigue life. The results indicated that the coolant channel location at 0.5 mm from the base induces minimum normal stress of 207.64 MPa, maximum fatigue life of 198560. However, the coolant location at 1 mm from the base experiences the temperature of 599.99 ^{0}C, which corresponds to normal stress of 208.95 MPa, fatigue life of 191340 cycles. This is considered to be the best among the coolant channel locations.

VI. REFERENCES

[1]. MLevin, BKarlsson; Fatigue behaviour of saffil-reinforced aluminium alloy (AA6061);1993; Volume24,Issue3, Pages 288-295.

[2]. JCollot et alReview of New Process Technologies in the Aluminum Die-Casting IndustryMaterials and Manufacturing Processes, 200116(5): p595-617.

[3]. QHan, and SViswanathan, Analysis of the mechanism of die soldering in aluminium die castingMetallurgical and Materials ransactions, 200334(1): p139-146.

[4]. ASrivastava, VJoshi and R Shivpuri; 2004; Computer modelling and prediction of thermal fatigue cracking in diecasting toolingIntJWear 256: 38-43.

[5]. DSchwam, JFWallace and SBirceanu; 2004; Effect of design factors on thermal fatigue cracking of die casting diesDE-FC07-00ID138486,US Department of Energy, Washington, DC.

[6]. DNovovic, RCDewes and DKAspinwall;2004; The effect of machined topography and integrity on fatigue lifeIntJMach Tools Manuf44 :125-134.

[7]. MOkayasu; 2009; Comparison of mechanical properties of die cast aluminium alloys: cold vshot chamber die casting and high vslow speed filling die castingIntJCast MetRes22: 324-381.

[8]. SAqida etal., Thermal fatigue properties of laser treated steelsInternational Journal of Material Forming, 20103(1): p797-800.

[9]. J.J.Moverare,; DGustafssonHold-time effect on the thermo-mechanical fatigue crack growth behaviour of inconel 718MaterSciEngA 2011, 528, 8660–8670.

[10]. SChang, K.Huang, and YWang, Effects of thermal erosion and wear resistance on AISI H13 tool steel by various surface treatmentsMaterials Transactions, 201253(4): p745-751.

[11]. DKlobˇcar.; LKosec; J.Tušek; Thermo fatigue cracking of die casting diesEngFailAnal2012, 20, 43–53.

[12]. IKoutiri, , et al., High cycle fatigue damage mechanisms in cast aluminium subject to complex loadsInternational Journal of Fatigue, 201347: p44-57.

[13]. DMatiskova,.; SGaspar,.; LMura,Thermal factors of die casting and their impact on the service life of moulds and the quality of castingsActa PolytechHung2013, 10, 65–78.

[14]. DMatiskova,.; SGaspar,.; LMura,Thermal factors of die casting and their impact on the service life of moulds and the quality of castingsActa PolytechHung2013, 10, 65–78.

[15]. Fazliana Fauzun, SNAqida, SNaher and DBrabazon;2014; effects of thermal fatigue on laser modified H13 Die Steel; Journal of mechanical engineering and sciences(JMES);ISSN:2289-4659; volume 6, pp975-980.

[16]. Xu, W.; Li, W.; Wang, YExperimental and theoretical analysis of wear mechanism in hot-forging die and optimal design of die geometryWear 2014, 318, 78–88.

[17]. Qian wan, Haidong Zhao and Chun Zou; 2014; effect of micro porosities on fatigue behavior in Aluminium die casting by 3D x-ray tomography inspection; doi.org/10.2355/isijinternatinal.

[18]. OAmmar,; NHaddar,; LRemy, Numerical computation of crack growth of low cycle fatigue in the 304l austenitic stainless steelEngFractMech2014, 120, 67–81.

[19]. IVicario, JKIdoiaga, EArratibel and PCaballero;2015; Development of HPDC advanced dies by casting with reinforced tool steels; International Journal of manufacturing Engineering;doi.org/10.1155/2015/287986.

[20]. CChen; YWang; Energy-based approach to thermal fatigue life of tool steels for die casting diesIntJFatigue 2016, 92, 166–178.

[21]. Xu Li, Bao-sheng Liu, Li-feng Hou and Ying-hui Wei;2017; Failure investigation of an AlSi9Cu3 Alloy Die-Cast Cavity Insert; Journal of failure analysis and prevention; issue6.

[22]. Ibrahim Ozbay, Tamer Aydiner, Gurkan Yilmazoglu and Hafize Celik;2019; Aluminium high pressure Die casting application on rear frame rails; European mechanical science; e-ISSN: 2587-1110.

[23]. Federico Simone Gobber, Andrea Giuseppe Pisa and Mario Rosso;2019; design of a Test Rig for the characterization of thermal fatigue and soldering resistance of the surfaces of tool steels for high pressure die casting dies; Steel research International: doi.org/10.1002/srin.201900480.

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