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Thermal Effect on the Automobile Piston: A Review

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Abstract

Background/Objectives: Mechanical and thermal properties of aluminum-based piston alloys are mainly depend on the heat treatment. Conventional heat treatment techniques are also not resulted to that level where it can be used for piston of downsized engine. **Methods/Statistical Analysis**: Around 30 papers were reviewed to understand the thermal effects and consequences on the Al Si piston alloy. **Findings:** From the literature it can be understood that two-step solution treatment of the Al Si alloy resulted the good mechanical properties then the single step solution treatment. Heat treatment at 540°C for 8 h and aging at 190°C for 8 h is correctly choice to achieve optimum mechanical properties by heat treatment. To calculate the temperature effect and heat transfer to the engine piston crown, the spatial and time averaged combustion side boundary condition is a most favorable and suitable treatment method within engineering approximations. For temperature and thermal stress distributions for a coated surface piston crown, the coating surface temperature increased with coating thickness by decreasing rate and the best results are at 1 mm coating. Application/Improvements: The coated piston has low thermal conductivity then the uncoated piston.

Keywords: Al-Si Piston Alloy, Heat Treatment, Mechanical Properties, Thermal effects, Thermal Properties

1. Introduction

It is important that the piston must have enormous strength and heat resistance properties to resist gas pressure and inertia forces. It should have minimum weight to minimize the inertia forces and should have rigid construction to endure thermal, mechanical distortion and sufficient area to avoid undue wear[1]. Automobile piston is an extremely key part of combustion engine, the output of automobile engine strongly depends on piston performance. This is the basis that it is important to design this part of combustion engine, particularly when design of engine is modified/changed[2–4]. Also modern research work on the downsizing of the engine which benefitted not only reduction in CO_2 but also reduction in the energy consumption by decreasing the swept volume. While on the other side there are lot of complications in downsizing the engine: Affecting the thermal loading (Mean effective pressure), mechanical loadings, high levels of stresses in the combustion chamber and many more. As in downsizing of piston up to 13% resulted in increment by 41.7% of the translation vector displacement and Huber–Mises stresses increased by 35.9%[5]. It is observed that AlSi alloy have been widely used in aerospace and automobile thermal applications to satisfy the increasing demand on environmental pollution issues, good mechanical and thermal properties, light weight structures, environmental and other requirements[6–8]. But to manufacturing the automotive and aerospace components the basic alloys are unbeneficial and may not fulfill the basic requirements of those and produced various unwanted stresses in components during the manufacturing by using virgin alloys[9]. These requirements can be achieved by using latest heat treatment techniques. Heat Treatment is the controlled process for heating and cooling of metals to change their mechanical and physical properties without altering the shape and design of the product[10]. Heat Treatment is often related to improve the mechanical strength of metals. But can also be utilized to modify and improvement in some manufacturing objectives:

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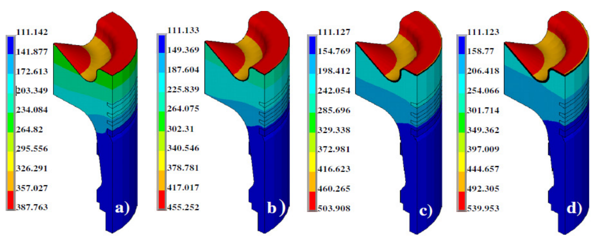
Machining, formability and regain ductility after cold working process of the product[11]. Heat Treatment operations has significantly impact on thermal, mechanical and fatigue behaviors especially at room temperature but not any significant effect on thermo-mechanical fatigue[12]. The conventional T6 ("solution-quenching-aging") treatment with EN AW-2618A alloy, containing 0.12wt% Zr soaked at 250°C, up to 50 h resulted high Hardness measurements, good microstructural characterization and better high temperature compression. Also giving evidence of significant improvements connected to controlled formation of Zr-based precipitates[13]. Annealing can cause the intermetallic compound which leads to reduce the coating wear resistance if it performed at 450^{0}C and above temperture[14]. By increasing the temperature of AlSiCuMg piston alloy from 180^{0}C to 190^{0}C, the eutectic silicon particles cause to improve tensile strength and thermal diffusivity of the piston alloy and also resulted in the 3% more thermal conductivity[15]. While the artificial aging in temperature range of 170–210^{0}C on the AlSiMg piston alloy resulted a small increment in the yield strength but Cu containing aluminum piston alloys resulted a decrement in yield strength[67]. In this review paper the focus was on the heat treatment best suited for good mechanical properties and the thermal effect on the Al-Si piston alloy.

2. Heat Treatment

For 332 aluminum piston alloys, single step T6 heat treatment at 495^{0}C/6 h resulted increment at 5.96%, 20.42% of the hardness and tensile strength respectively while a decrement of 3.97% in elongation of the alloy. But two step T6 heat treatment at 495^{0}C/2 h followed by 515^{0}C/4 h resulted to increase 6.64% and 16.01% the hardness and tensile strength respectively and decrease the elongation by 4.67% of the 332 aluminum piston alloy. These results are on the comparison basis for the same as cast 332 aluminum alloy. While in this work both heat treatment processes followed by hot water quenching at 75–90^{0}C and artificial aging at 250^{0}C for 4 h[17]. For observing the effects of heat treatment solutions and artificial aging on the microstructure and mechanical properties in die cast AlSiCu alloy having 1wt:% Fe resulted that in order to achieve improvement in ductility and strength, the alloy must be controlled at low level of temperatures then the normal temperature required for carrying these two techniques[18]. It is important to find the critical timing for aging to achieve optimum results. As it was observed that the hardness of the piston alloy increases from HV10 96.5 to 151.1 when aging for 8 hours but beyond this time limit the hardness will be decrease because of over aging. Also for aluminum piston alloy, increasing the hardness leads to increase the wear resistance and thus for optimum results of the alloy the heat treatment solution must be performed at 540°C for 8 h and aging at 190°C for 8 h[19]. The continuous supply of the temperature in T6 heat treatment solution causes to change the hardness and tensile strength of the forged piston. As it was observed for the forged piston quenched and aging in the range of 25–220°C and T6 heat-treated ranges from 200–300°C for 1week reduced the proof and ultimate tensile strength and hardness of it but elongation to failure and strain hardening exponent improved[20]. In conclusively the microstructure and mechanical properties of the AlSi piston alloy majorly depends on the temperature exposure and time of heat treatment solutions and aging operation. Also these two parameters (temperature exposure and time) of the heat treatment techniques change the microstructure, mechanical and thermal properties of the aluminum piston alloy[21]. Thus it is of vital importance to focus whole heat treatment operations and factors (temperature and time) to obtained optimum and significant results for mechanical and thermal properties and manufacturing objectives for the aluminum piston alloy. Because the information only relating to heat treatment solution and aging are not sufficient to decide any finalize statement[16].

3. Thermal Effect

The increasing the test temperature causes to reduce the fatigue strength of eutectic Al-Si piston alloy. The best influence of test temperature can be investigated by chemical composition, process route and of mechanisms of fracture found in broken specimen[22]. As in the temperature range 25–350^{0}C, the fracture mechanism and tensile strength behavior was examined of in-situ 4wt:% TiB_2/AlSi composite. The tensile strength of the composite showed higher modulus then the matrix alloy at all testing temperature while the ductility observed to be lower than that of matrix alloy at temperature ranges from 25–200^{0}C. But not any noticeable difference was at 350^{0}C. Also it was observed that the fracture was subjected by cracked silicon particles and separated TiB_2 particles, while decohesion at particles matrix influence was dominant at 350 ^{0}C[23]. The temperature and thermal stresses distribution analysis were examined for an aluminum piston crown coated with plasma sprayed magnesia stabilized zirconia. The coating thickness ranges from 0.2 mm to 1.6 mm without considering the bond coat layer. It results that the coating surface temperature increased with coating thickness by decreasing rate, the maximum temperature is 64.3% for 1 mm coating thickness when compared to uncoated piston crown as shown in Figure 1. Also coating causing to increase the combustion chamber temperature which resulted to improve thermal efficiency of the diesel engine.



(a) (b) (c) (d)

Figure 1. Temperature distribution at. (a) 0.4 mm. (b) 0.8 mm. (c) 1.2 mm. (d) 1.6mm.

While due to coating and increasing the temperature on coated piston crown, the value of maximum normal stress increased at about two and three times then the substrate and uncoated piston crown respectively. The maximum shear stress value is nearly double that of the substrate surface as shown in Figure 2[24].

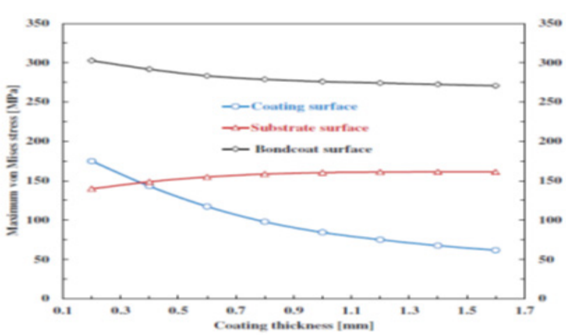


Figure 2. Maximum normal stress for different aspects of piston.

Also when the thermal analysis compared for uncoated diesel piston manufactured by AlSi alloy and steel coated with MgO-ZrO_2 materials by means of commercial code namely ANSYS. This resulted low thermal conductivity in the coated piston with material and an improvement of 48% and 35% for AlSi alloy and steel respectively as shown in Figure 3[25].

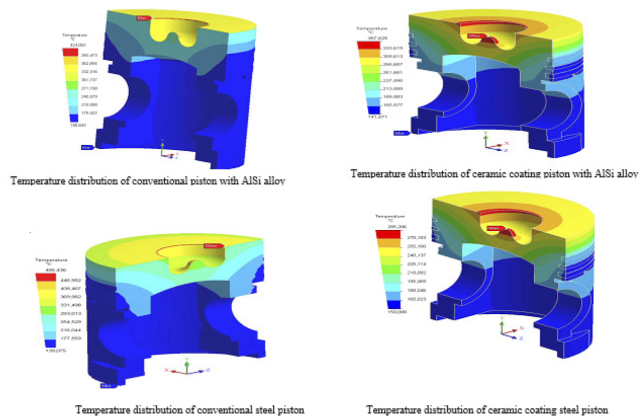


Figure 3. Temperature distribution of pistons.

While for the Spark Ignition (SI) engine piston with partial ceramic coating for examining the effects of coating thickness and width on temperature and stress distribution, these results were also compared to uncoated piston. In results, the coating surface temperature increased with increasing the thickness in a decreasing rate. The piston with 0.4 mm coating resulted in the maximum increment of surface temperature up to 82°C. The minimum value of normal stress achieved at 1 mm thickness but beyond this it showed reverse trend. On the basis of results shown in Figure 4, the optimum coating thickness was found to be near 1 mm[26]. On the other side to calculate the temperature effect and heat transfer to the engine piston crown. The spatial and time averaged combustion side boundary condition is a most favorable and suitable treatment method within engineering approximations[27].

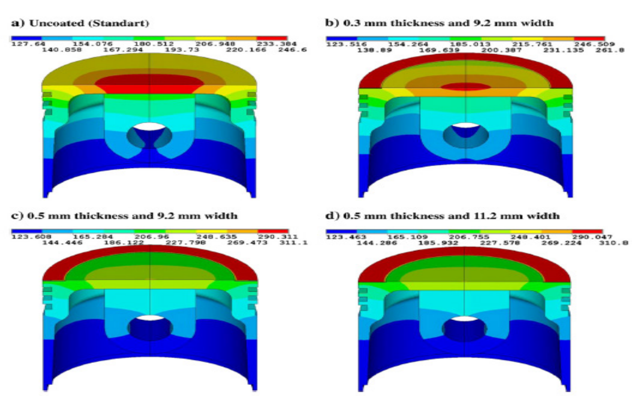


Figure 4. Coating thickness and width on temperature.

High Frequency Induction heating internally cool by permanent water flow to test fatigue of automotive engine pistons. Simple and economical tests to calculate the production scattering and more simply calculate the fatigue failure. This fatigue bench is best suitable for all the types of piston: Only the coil should be modified as per the bowl diameter[28].

4. Future Challenges

The engineering world is converted in small weight and lessen in dimension of the engineering components while maintaining the performance at the bar or even better. Still there are many challenges to achieve these two objectives. Mainly the introduction of new composites may help to overcome the obstacles. Many researchers concluded new composites having better properties and suitable in performance, but the casting, fabrication, machining and heat treatment techniques may alter the properties.

Downsizing of the engine is the latest technology in the automobile world where it has many advantages but still there are some areas where research is important for more advantageous. The downsizing of the engine produced less dangerous environment pollutants, boosting the output power and reduction in the dimension of it. Due to which higher amount of stresses are generated and sometime downsized engine parts may fail prematurely. The Al Si virgin alloys may not withstand to the amount of stresses produced in the downsized engine. The conventional heat treatment techniques are also not resulted to that level where it should be. It is necessary to research to develop new Al Si alloys and new heat treatment techniques for making this new technology more advantageous.

5. Summary and Conclusion

Al–Si based alloys have been widely used in automotive piston and other thermal applications because of good mechanical and thermal properties, lightweight structures, environmental and other attractive properties. But to manufacturing the automotive piston the basic Al-Si alloys are unbeneficial and may not fulfill the basic requirements of piston and produced various unwanted stresses in components during the manufacturing by using virgin alloys. On the basis of literature used in this this work following are the conclusions:

Mechanical and thermal properties of aluminum-based piston alloys (eutectic, hypereutectic alloys) chiefly depend on the heat treatment. Two-step solution treatment of the Al Si alloy resulted in the good mechanical properties then the single step solution treatment. Heat treatment at 540°C for 8 h and aging at 190°C for 8 h is correctly choice to achieve optimum mechanical properties by heat treatment. Best influence of test temperature can be investigated by chemical composition, process route and of mechanisms of fracture.

To calculate the temperature effect and heat transfer to the engine piston crown it was concluded that spatial and time averaged combustion side boundary condition is a most favorable and suitable treatment method within engineering approximations. For temperature and thermal stress distributions in a plasma sprayed magnesia-stabilized zirconia coating on an aluminum piston crown. The coating surface temperature increased with coating thickness by decreasing rate and the best results are at 1 mm coating. The coated piston has low thermal conductivity then the uncoated steel piston.

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