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Analysis of Crown Shrinkage in Gravity Die Cast Aluminium Alloy LM 13 Piston

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Abstract

Background/Objectives: Optimization of process parameters to obtain shrinkage free engine piston based on Al-Si casting alloy LM 13 fabricated by gravity die casting. **Method/Statistical Analysis:** Experimental analysis of design and process parameters like riser sleeve size, center core temperature, pouring metal temperature and solidification time was carried out on Al-Si casting alloy LM 13 based engine piston fabricated by die casting technique. The die casting experiments with different solidification time 90, 120 and 150 seconds and volume of molten metal consumed by different sleeve size were carried out to obtain optimum conditions to produce shrinkage free engine pistons. The die casted engine piston were sectioned and checked for shrinkage at different design and process parameters. **Results/Findings:** The results showed that there is an effect of centre core temperature towards the shifting of shrinkage from the crown to riser. The center core temperature should not be maintained below 200°C and should be in the range of 200 - 238°C. But it cannot be concluded that the crown shrinkage is only due to the centre core temperature. The molten metal Al-Si is less dense as a liquid than as a solid so castings shrink upon cooling, which can leave a void at the last point to solidify. Risers prevent this by providing molten Al-Si alloy to the casting as it solidifies, so that the shrinkage forms in the riser and not the in engine piston casting. It was found that the size of sleeve size is indirectly proportional to the occurrence of crown shrinkage and increase in size of sleeve size reduces the chances of shrinkage. Engine piston section results showed the shrinkage shifting from casting to riser side by increasing the sleeve size. However the effect of different solidification time and pouring metal temperature was not so significant on the occurrence of shrinkage. **Applications/Improvements:** The optimized center core pin temperature and riser sleeve size successfully prevented the shrinkage formation in the Al-Si casting alloy LM 13 engine piston casting. This not only helps in improving the casting quality but also in increasing the production.

Keywords: Al-Si Alloy, Engine Pistons, Gravity Die Casting, Shrinkage, Solidification Time

1. Introduction

A piston is a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. Early day's pistons were made of cast iron. But as the advances started taking place in the modern technology has led to the development of Al-Si casting alloy LM 13 to meet the demand of increasing engine speeds. The pistons are mostly made up of casting technique but for better strength and fatigue life, some racing pistons may be forged instead[1,2]. Casting is often chosen as manufacturing technique due to its various advantages. The casting technique is not only used to fabricate monolithic metals but also metal matrix composites[3,4]. In recent gravity die

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casting has been replacing the conventional sand casting technique owing to its better mechanical properties, surface finish and repetitive usage of same die.

The gravity die casting process begins by preheating the mold to ease the flow and reduce thermal damage to the casting. The mold cavity is coated with a refractory material or a mold wash, which prevents the casting from sticking to the mold and prolongs the mold life. Any sand or metal cores are then installed and the mold is clamped shut. Molten metal is then poured into the mold. Soon after solidification the mold is opened and the casting removed to reduce chances of hot tears. The process is then started all over again, but preheating is not required because the heat from the previous casting is adequate and the refractory coating should last several castings. Because this process is usually carried out on large production run work-pieces automated equipment is used to coat the mold, pour the metal, and remove the casting. However if not cast properly the castings can have defects like cold shut, porosity, shrinkage and inclusions. Shrinkage occurs during solidification as a result of volumetric differences between liquid and solid state. For most aluminium alloys, shrinkage during solidification is about 6% by volume. Lack of adequate feeding during casting process is the main reason for shrinkage defects. By making sure that the volume of the casting is adequately fed by risers, Shrinkage defects can be avoided[5-7].

The present scope of study is to determine the parameters which influence the shrinkage defect and possible suggestion to rectify it. Crown Shrinkage is the depression typically internal to the casting that is caused by a molten island of material that does not have enough feed metal to supply it. Shrinkage cavities are characterized by a rough interior surface. The shrinkage causes due to the irregular solidification and improper water cooling to the die.

2. Experimental Details

The experiment was carried out to determine the inference for the crown shrinkage in piston castings. The parameters influences the castings such as water flow rate, water inlet temperature to the die, water outlet temperature from the die, die body temperature, centre core temperature; crown temperature was observed and recorded to find the reason for the crown shrinkage. The castings are marked as a sample and followed for machining and inspection.

2.1 Iteration No. 1

The first experiment done to determine the parameter affecting crown part which gives the effect water inlet temperature, water outlet temperature from the die, die body temperature, centre core temperature, crown temperature on piston quality. But the clear inference is not obtained from the experiment. The activities such as air blown to die cavities and white and black coatings are observed during the experiment. We found the particular causes. So we changed the variable input parameters of castings such as solidification timing, sleeve size, pouring metal temperature, centre core and die at three stages of temperature.

2.2 Iteration No. 2

As already explained, the first variable which is changed is die body and centre core temperature of the die. The readings at a definite interval of time that is at different stages are taken and are shown in Table 1-3. Then the pistons are cross sectioned perpendicular to the axis and observed the shift of shrinkage towards the riser. Based on the shift of the shrinkage, the inference for the crown shrinkage is obtained.

Based on the Table 1, it is clear that the center core temperature should not be maintained at the range between 65°C - 100°C. Let us discuss what would happen if the centre core temperature maintained beyond this value.

2.3 Iteration No. 3

2.3.1 Riser Sleeve

Riser sleeves are strong, low-density, tube sleeves of insulating refractory material. They are specifically designed to promote efficient feeding of aluminium castings.

Table 1. Center core of the die at low temperature

Sl. No.	Center Core	
	First cavity	Second cavity
Units	Temperature, °C	Temperature, °C
1	65	60
2	73	76
3	80	83
4	88	87
5	90	95

Table 2. Center core of die at medium temperature

Sl. No.	Center Core	
	First cavity	Second cavity
Units	Temperature, °C	Temperature, °C
1	172	178
2	177	210
3	177	213
4	208	206
5	172	191

Table 3. Center core of die at high temperature

Sl. No.	Center Core	
	First cavity	Second cavity
Units	Temperature, °C	Temperature, °C
1	180	210
2	220	226
3	224	228
4	231	234
5	232	238

Benefits:

- Sleeve withstands rough handling and moulding.
- Increased casting yield.
- Reduced metal treatment costs.
- Reduced riser contact area.
- Reduced casting cleaning costs.
- Low smoke and fume.
- Sleeves are easily cut to special heights.

2.4 Experiment Done by Varying Riser Sleeve Size

There are three types of sleeve used such as 4, 4A, 4C based on the inner diameter and taper angle of sleeve. The riser sleeves are made up of ceramic material to withstand the heat (i.e. the riser sleeve maintains molten metal in liquid state for long duration to feed the metal to casting). An experiment is carried out to predict the change in shrinkage shift from crown to the riser of the piston casting (Figure 1-3).

An experiment made by using the riser sleeve size 4 as shown in Figure (a) and then by using the riser sleeve size 4A as shown in Figure 4 (b) and finally experiment conducted by using the riser sleeve size 4c as shown in Figure 4 (c). From this experiments the shrinkage shift from the crown surface of the piston to the riser. The increase in sleeve size decreases the crown shrinkage in piston castings. But it affects the yield of molten aluminium alloy (Table 4). So, the standard sleeve size 4 is used to make the yield improvement in the molten aluminium alloy.

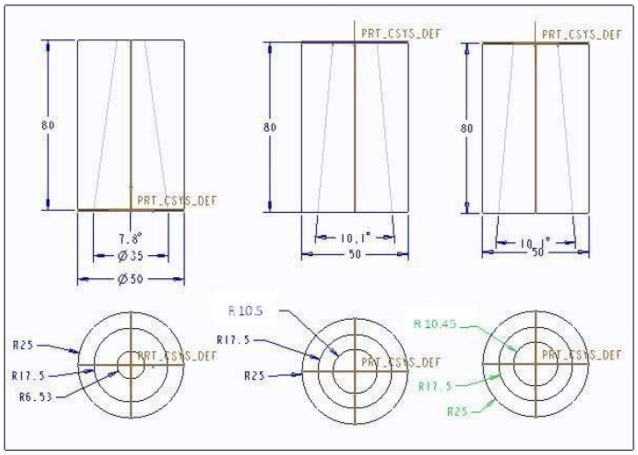
Figure 1. Riser Sleeve size 4.

Figure 2. Riser sleeve size 4A.

Figure 3. Riser sleeve size 4C.

2.5 Experiment Done by Varying Pouring Metal Temperature

Next variable parameter is pouring metal temperature. Although the pouring metal temperature does not plays



(a) (b) (c)

Figure 4. Drafting of **(a)** Riser sleeve size 4, **(b)** Riser sleeve size 4A, **(c)** Riser sleeve size 4C.

Table 4. Volume of molten metal consumed by riser sleeve

Riser sleeve size specifications	Volume of molten metal in sleeve, mm3
4	1,54,901.00
4A	2,01,146.00
4C	2,00,501.00

predominant role because the pouring metal temperature is already maintained at a range between 730°C -740°C. But certain times this plays a role because there may be chance of temperature get reduced below 730°C so it is account.

2.6 Experiment Done by Varying Solidification Time

Casting geometry, material and process determine the solidification time of a casting. In simple terms the Chvorinov's rule[8,9] establishes that under otherwise identical conditions, the casting with large surface area and small volume will cool more rapidly than a casting with small surface area and a large volume.

3. Results and Discussion

The effects of design and process parameters on the occurrence of shrinkage in the Al-Si casting alloy LM 13 based engine piston casting are discussed below.

3.1 Centre Core Temperature

From iteration No. 2, we found that there is an effect of centre core temperature towards the shifting of shrinkage from the crown to riser (Figure 5-7). Based on the three stages of the centre core temperature cross sectioned piston it may be concluded that the centre core temperature should not be maintained at very low temperature. It should be maintained at the optimum level of 200°C-238°C. But it cannot be concluded that the crown shrinkage is only due to the centre core temperature. So the experimental analysis was made for other variable parameters such as sleeve size, pouring metal temperature, solidification timing.

3.2 Riser Sleeve Size

From iteration No. 3, we found that the effect of increase in size of riser sleeve would increases the shifting of

Figure 5. Cross section of second cavity piston casting at low centre core temperature with gross crown shrinkage.

Figure 6. Cross section of 2nd cavity piston casting at medium centre core temperature.

Figure 7. Cross section of 2nd cavity piston casting at high centre core temperature.

Figure 8. Piston casting Cross section with 4 riser sleeve size.

Figure 9. Piston casting Cross section with 4C riser sleeve size.

shrinkage from crown to the riser of the piston casting (Figure 8-9). So, the size of sleeve size is indirectly proportional to the occurrence of crown shrinkage i.e. if the size (diameter) of sleeve is greater, then the probability of occurring of crown shrinkage in the riser. Otherwise, the increase in volume consumed reduces the chance of shrinkage formation in the piston casting crown surface.

3.3 Pouring Metal Temperature

From the iteration No. 4, it is clear that there is no effect of pouring metal temperature towards the crown shrinkage (Figure 10).

3.4 Solidification Time

From the iteration No. 5, it is clear that there is no effect of Solidification time towards the crown shrinkage by varying solidification time to 90 secs, 120 secs and 150 secs (Figure 11 - 13).

Figure 10. Piston casting cross section sample when pouring metal temperature is about 740°C and 720°C respectively.

Figure 11. Piston casting cross section sample when solidification time 90 secs is given.

Figure 12. Piston casting cross section sample when solidification time 120 secs is given.

Figure 13. Piston casting cross section sample when solidification time 150 secs is given.

4. Conclusion

Parametric study for the crown shrinkage in piston casting has been studied and following were observed:

- When the centre core temperature is low (65-95 °C) the shrinkage is formed at the crown of piston casting, if it is at medium temperature (175-195 °C) then the shrinkage is shifted from the crown to riser.
- When the volume of the riser sleeve increases the shrinkage moves away from the crown of the piston casting to the riser.
- There is no relation with respect to the pouring metal temperature.
- There is no relation with respect to the solidification time.

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