CHAPTER 6

CONCLUSIONS

6.1 CONCLUSIVE SUMMARY

An attempt was made in this research work to study the effect of solidification conditions on metallurgical features and their impact on the mechanical properties of Al-Si alloy castings. Two Aluminium-Silicon alloys A413 and A380 were chosen for the present study. Gravity die casting method was chosen for the present study as it simple in the process and does not involve any external influence on the casting like applying pressure, centrifugal force, etc.

Experiments were conducted on chosen Al-Si alloys under two different cooling conditions viz., (i) air cooling and (ii) water cooling with the optimal combinations of influencing parameters. The thermal history of the castings and mold were recorded during entire casting process. Serial IHCP algorithm was extended for computing the multiple heat flux components at the metal-mold and mold-ambient interfaces. The disparity in the rate of heat transfer from one place to another in the mold will result in the spatial variation of microstructure within the casting. This would lead to non-homogeneity in the properties of castings. The peak heat flux values of metal-mold interface were used as a critical parameter for assessing the spatial variation of interfacial heat transfer during solidification. The influence of cooling conditions on spatial variation of interface heat flux and its effect on the microstructure and mechanical properties were analysed for both A413 and A380 Al-Si alloy castings. From the experimental and computational results the following conclusions were drawn-

- The thermal profile of the molds showed that the temperature of the mold was too high with **air-cooled casting** when compared to **water-cooled casting** method.

    i. In the case of **air-cooled casting** the maximum temperature of ~457°C was observed for A413 alloy and ~442°C for A380 alloy.

    ii. The corresponding maximum temperature observed in the case of **water-cooled casting** was ~163°C for A413 alloy and ~160°C for A380 alloy.

- The temperature profile of the castings revealed that the **local solidification** time of the melt was very short with **water-cooled casting** when compared to **air-cooled casting**, at both the mid thermocouple location T_M and outer thermocouple location T_O.

    i. In the case of **water-cooled casting** it was observed that the time taken for solidification was *~23s* at the mid location T_M and *~11.5s* at the outer location T_O for A413 alloy. The corresponding time taken for solidification was found to be *~17s* at T_M and *~9.5s* at T_O for A380 alloy.

ii. In the case of **air-cooled casting** the time taken for solidification were ~*92.5s* at T_M and ~58*s* at T_O for A413 alloy; ~55*s* at T_M and ~31*s* at T_O for A380 alloy.

- The magnitudes of **peak interfacial heat fluxes** are much greater in the **water-cooled casting** method when compared to **air-cooled casting**.

i. **Peak interfacial heat flux** magnitude at the bottom, middle and top regions were found to show a decreasing trend in the case of **air-cooled casting** method. This leads to the **spatial variation** of heat flux in the axial direction of the cylindrical cast, due to uneven air gap formation and uneven expansion of the mold. The respective values were found to be -*2284* kW/m^2, -*1741*kW/m^2 and -*1267* kW/m^2 for A413 alloy. The corresponding values were found to be -*2182* kW/m^2, -*1623* kW/m^2 and -*1241* kW/m^2 respectively for A380 alloy.

ii. In the case of **water-cooled casting** method, the peak values of interfacial heat flux in the three regions bottom, middle and top were found to be -*3647* kW/m^2, -*3561* kW/m^2 and -*3448* kW/m^2 for A413 alloy. The corresponding values were -*3399* kW/m^2, -*3303* kW/m^2 and -*3191* kW/m^2 for A380 alloy.

iii. It can be observed that the **spatial variation** of **interfacial heat flux** along the vertical direction of mold during the solidification was almost negligible in the **water-cooled castings** of both the Al-Si alloys. This will improve the cast quality and will give more uniform micro structure within the cast along the vertical direction.

- Metallurgical evaluation results of **air-cooled casting** revealed the existence of **spatial variation** in microstructural features such as **SDAS** and the size of **eutectic silicon scripts** along the vertical direction of the casting. **Spatial variation** in the microstructural features was more or less negligible in the **water-cooled casting** as a result of minimal spatial variation of interfacial heat flux.

  i. In the case of **air-cooled casting, SDAS** was found to be *30.4μm, 42.62μm & 65.33μm* at the bottom, middle and top regions respectively for A413 alloy and *21.78μm, 34.54μm & 54.62*μm for the corresponding regions of A380 alloy.

  ii. In the case of **air cooled casting,** the size of the **eutectic scripts** was found to be *46.53μm, 73.45μm & 126.95μm* at the bottom, middle and top regions for A413 alloy; *51.80μm, 61.90μm & 110.51μm* for the corresponding regions of A380 alloy.

  iii. In the case of water cooled casting, **SDAS** was to be *18.27 μm, 19.66 μm & 21.81 μm* at the bottom, middle and top regions respectively for A413 alloy and *19.19μm, 20.54μm & 21.62μm* for the corresponding regions of A380 alloy.

iv. In the case of **water cooled casting,** the **size of the eutectic silicon scripts** was found to be 42.10*μm, 47.63μm & 48.62μm* at the bottom, middle and top regions respectively for A413 alloy and *38.98μm*, 37.62*μm & 40.03μm* for the corresponding regions of A380 alloy.

- Comparatively well refined grains were found in the **water-cooled castings** of both the Al-Si alloys studied in the present work.

- The **Ultimate Tensile Strength (UTS)** of the **water-cooled castings** was found to be greater at both the outer (*T-S*) and inner (*T-C*) regions when compared to **air-cooled castings** for both the Al-Si alloys, due to highly refined microstructure.

i. In the case of **water cooled castings** the magnitudes of **UTS** were found to be *300.30 MPa* at the *outer* region of the cast and *282.95 MPa* at the inner region of the cast for A413 alloy. The corresponding values were found to be *364.77 MPa* at the outer region and 3*25.42 MPa* at the inner region for A380 alloy.

ii. For the **air-cooled castings** these values were found to be *257.75 MPa* at the outer and *220.53 MPa* at the inner for A413 alloy; *305.13 MPa* at the outer and *271.38 MPa* at the inner for A380 alloy.

- Similarly **Yield Strength** (**YS)** was also found to be higher at both outer and inner regions of the **water-cooled castings** when compared to **air-cooled castings** for both the Al-Si alloys**.**

    i. In the case of **water-cooled casting** the magnitudes of YS were found to be *125.31 MPa* at the outer region *& 97.7 MPa* at the inner region for A413 alloy. The corresponding values were found to be *145.81 MPa* at the outer *& 108.62* MPa at the inner for A380 alloy.

    ii. For the **air-cooled castings** these values were found to be *87.5 MPa* at the outer region & *74.14 MPa* at the inner region for A413 alloy; *97.52 MPa* at the outer *& 62.48 MPa* at the inner for A380 alloy.

- The **ultimate compressive strength** of the **water-cooled castings** was found to be higher at both the outer (*C*-*S*) and inner (*C*-*C*) regions compared to **air-cooled castings** for both the Al-Si alloys.

    i. The magnitudes of ultimate compressive strength of the **water-cooled castings** were found to be *343.19 MPa* at the outer region *& 320.2 MPa* at the inner region for A413 alloy; and *404.19 MPa* at the outer *& 380.88 MPa* at the inner for A380 alloy.

    ii. For the **air-cooled castings** these values were found to be *299.8 MPa* at the outer region *& 265.1 MPa* at the inner region for A413 alloy; *335.01 MPa* at the outer *& 328.8 MPa* at the inner A380 alloy.

- The **impact strength** of **air-cooled casting** was to be restored compared to **water-cooled casting** of both the Al-Si alloys. It has also been found that inner regions (*I-C*) have good impact strength compared to outer regions *(I-S).*

    i. The magnitudes of impact strengths of **water-cooled castings** were found to be *2.5 J* at the outer region *& 3.25 J* at the inner region for A413 alloy; *2.15 J* at the outer *& 2.5 J* at the inner for A380 alloy.

    ii. For the **air-cooled castings** these values were measured as *3.8 J* at the outer region *& 4.25 J* at the inner region for A413 alloy; *3 J* at the outer *& 3.65 J* at the inner for A380 alloy.

- Wear test results show that the fast cooling (water-cooling) of cast considerably diminishes the **coefficient of friction** (COF). The coefficient of friction of the **water-cooled cast**ings of A413 alloy decreased by 20% at 10 N load and 27% at 20 N load compare to **air-cooled casting.** Similarly the coefficient of friction of the **water-cooled casting** of A380 alloy decreased by 20% at 10 N load and 30% at 20 N load compare to **air-cooled casting**.

Ultimately, it was understood that casting of Al-Si alloys with water-cooling technique is a potential method for achieving the higher solidification rate. Water-cooling not only increases the solidification rate, but also reduces the special variations in heat flux along the longitudinal direction in a vertically mounted mold which in turn eliminates the spatial variation in metallurgical features. Increase in solidification rate with water cooling technique enhanced the mechanical properties of the casting.

6.2 SCOPE FOR FURTHER RESEARCH

The following are the recommendations identified from the present research work.

- Estimated interfacial heat flux can be used as an input of other simulation softwares for predicting the solidification behaviour of the metal castings.

- The estimation of interfacial heat flux can be extended for the castings with complex geometry.

- The non-homogeneity of metallurgical and mechanical properties along the radial direction from the outer to inner zone is evident. A better alternate method / technique need to be identified / developed to bring homogeneity.

- This kind of study can be extended for the other casting methods which are having complex influencing parameters such as high pressure die casting, squeeze casting etc.