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Effects of Spray Angle on Spray Cooling of Extruded Aluminum Alloy Plate

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Abstract

Spray cooling technology relying on phase-change mechanism has a notable ability to remove high heat fluxes. Spray cooling can be used to transfer large amounts of energy through the latent heat of evaporation. Heat transfer rates much higher than can be attained in pool boiling are possible with spray cooling since the vapor can be removed from the surface more easily. Therefore, spray cooling has a number of applications in the various fields such as continuous casting process, electronics thermal control and metal quenching process which require a high flux cooling technique [1-3]. One important area which would benefit from spray cooling to improve heat removal is press quenching of extruded aluminum alloy plate.

Keywords: spray cooling, spray angle, heat transfer coefficient, aluminum alloy plate, equivalent stress;

1. Introduction

Heat transfer in spray cooling has been studied extensively throughout the world. Shaojun Zhang et al [4] studied the effects of spray distance and high-temperature steel plate’s surface temperature on heat transfer coefficient in spray cooling. Eric A. Silk et al [5] investigated the effects of surface roughness and spray inclination angle on spray cooling.

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In the past few years, studies [6-8] on the spray angle are focused on the spray angle itself and the coefficients of discharge and the spray cone angle, fruitful results were obtained by both experimental and numerical research. However, progress in the research of effects of spray angle on spray cooling has been very slow, especially in the field of metal press quenching. The analysis of the effects of spray angle on heat transfer is much more difficult and the direct numerical simulation is the best choice for theoretical study.

This paper attempts to make some numerical investigations on the effects of spray angle on spray cooling of extruded aluminum alloy plate to look for an optimal range of spray angle value that can improve the cooling performance. A commercial FVM code, Fluent, will be employed to calculate the temperature distribution within the cooled aluminum plate. The corresponding stress distribution is obtained with the help of MSC.Marc software.

2. Model Building

The cooling target is 300 mm × 10 mm section aluminum alloy plate, Fig 1 shows the simplified spray cooling model for analysis with nozzle arrangement. The pressure boundary condition at inlet and outlet is P = 101325 Pa. For the surface, no slip boundary condition is considered. SIMPLE algorithm is adopted as the pressure-velocity coupling solver. It is clear from the 2-D mesh model shown in Fig 2 that the mesh around the outlet of nozzle along the spray axis is locally fined to improve the computation resolution.

The spray operating pressure is 0.3 MPa, the orifice diameter of spray nozzle is 2 mm, the spray angles varied between 10º and 110º, the spray distance from the plate surface is 150 mm, the cooling time is 10 s, the gravity is neglected in the model.

The aluminum plate is assumed of uniform temperature distribution when it is extruded from the extruding machine. Therefore, the initial temperature distribution of the plate is set uniform, the temperature value is set 793 K. The material property is 6061 aluminum alloy.

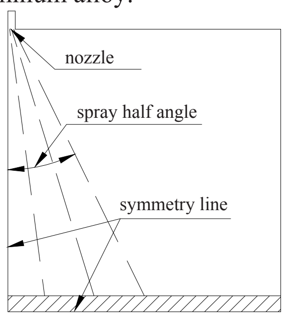

Fig.1. schematic diagram of simplified model for analysis

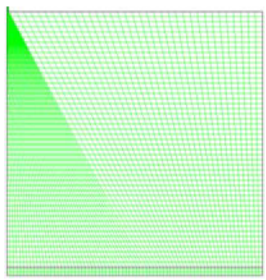

Fig.2. meshed model for analysis

3. Simulation Results And Analysis

The distribution of heat transfer coefficient on top surface at different spray angle is described in Fig 3, which indicates that the highest heat transfer coefficient is at the spray stagnation point (located at the central point of top surface) in all cases. With the distance from the stagnation point increasing, the heat transfer coefficient is on a decrease on the whole. From the Fig 4, it can be observed that the increase of cooling efficiency and cooling uniformity can be improved under an optimal range of spray angle, in this paper, the optimal range of spray angle is from 70º to 90º.

Heat transfer coefficient is a very important factor affecting the temperature change, therefore, it is can be seen from the Fig 5 and Fig 6 that the bigger the spray angle is, the more uniform the surface temperature distribution becomes, and when the spray angle is about 90º, the mean surface temperature reaches the maximum value. So increasing the spray angle can make contribution to cooling uniformity to certain extent, and cooling efficiency attained the highest at spray angle ranging from 70º to 90º.

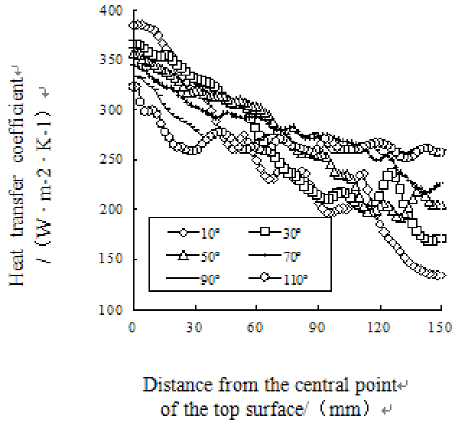

Fig.3. surface heat transfer coefficient distribution at different spray angles

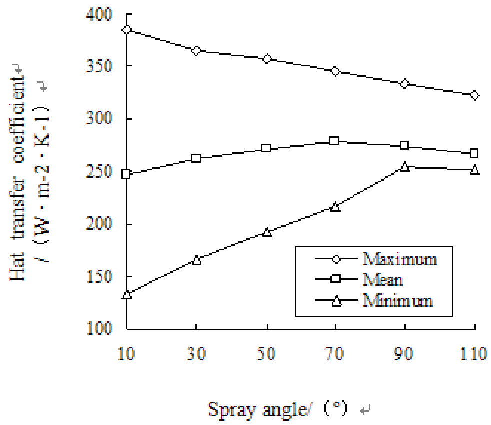

Fig.4. relationship between spray angles and surface heat transfer coefficient distribution

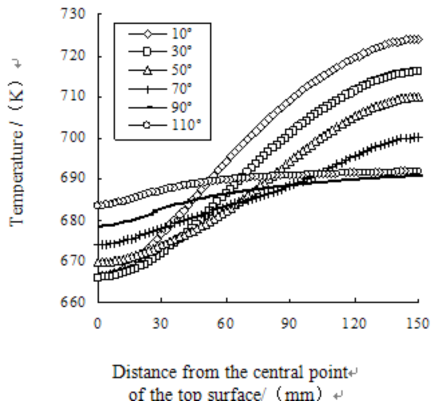

Fig.5. surface temperature distribution at different spray angles

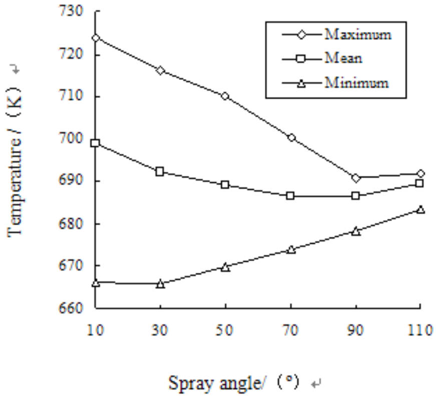

Fig.6. relationship between spray angles and surface temperature distribution

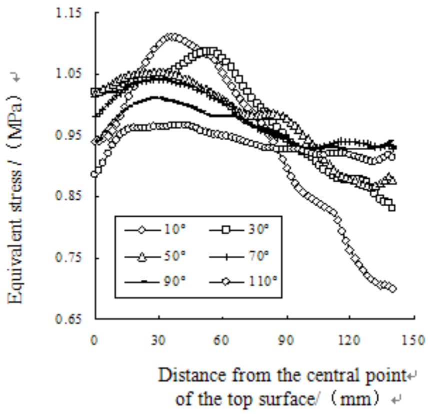

Fig.7. surface equivalent stress distribution at different spray angle(0~140mm from the cental point)

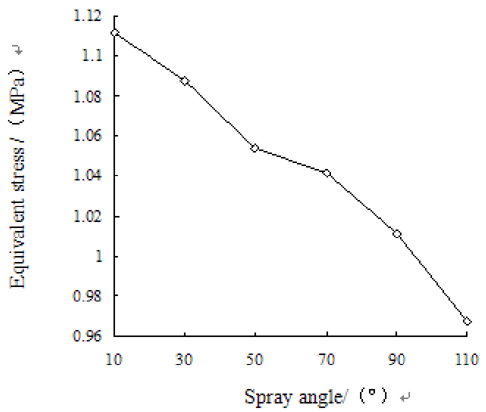

Fig.8. relationship between spray angles and maximum surface equivalent stress

From Fig 7 and Fig 8, which show the equivalent stress distribution and maximum surface equivalent stress on the top surface at different spray angles, it can be found that increasing spray angle can remarkably better the uniformity of the surface equivalent stress distribution and help lower the maximum surface equivalent stress, it is meaningful in keeping high quality and satisfactory shape of the product.

4. Conclusion

A numerical study of spray cooling of extruded aluminum alloy plate with an emphasis on spray angle effects on cooling performance has been presented. The analysis for the cooling process is a combination of FEM and FVM. The results show that increasing spray angle contributes to improving uniformity of surface temperature distribution, surface equivalent stress distribution and reduction of maximum surface equivalent stress obviously, and the spray cooling will be performed with higher thermal efficiency in a certain range of spray angle, the optimal range of spray angle is from 70ºto 90º in this paper.

Acknowledgements

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