EXPERIMENTAL AND NUMERICAL INVESTIGATION OF MOLTEN SALT BATH QUENCHING AND EVALUATION OF THE HEAT TRANSFER COEFFICIENT

Alper Keleşoğlu[1], Levent Sindel[1], Cengiz Zafer[1], Gökhan Lale[1], Mehmet Özdeşlik[1], Ümit Ünver[2]

[1]Sistem Teknik Industrial Furnaces R&D Center, 41420, Çayırova, Kocaeli, Turkey
[2]Yalova University, Faculty of Engineering, Department of Mechanical Engineering, 77200, Yalova, Turkey

Keywords: Salt Bath, Quenching, Heat Transfer Coefficient, Simulation

Abstract

Molten salt baths are widely using in the heat treatment industry. Considering the martempering and austempering applications in this field, molten salts are the most reliable technique for quenching applications in order to get homogenous microstructure and fine grains. On the other hand, new aviation steels require certain cooling rates in quenching process. In this work, the quenching process of Ni based superalloy is investigated under different molten salt bath temperatures. Cooling curves are obtained by the experiments and the numerical analysis is done to determine the heat transfer coefficient during the process. The results showed that the cooling rate is decreasing with increasing salt bath temperature. Also, heat transfer coefficient is found as a single constant value for all molten salt bath temperatures and in the range of the values which is implied in the literature.

1. Introduction

Regarding to the rapid development in aviation industry, the components of the system requires high temperature and pressure endurance during its service life. For this reason, thermo-physical properties and the creep-rupture characteristics of the components strongly depend on the microstructure of the alloy [1]. In order to achieve precise controlling of the process, fine grains, and homogenous microstructure, the selection of the heat treatment method is important [2]. For several applications, Ni-based superalloys are emphasised as solution annealed and precipitation hardened. The Inconel grades of the Ni-based superalloys are hardened with the precipitation of the gamma prime and carbides as a secondary phase inside the metal matrix. The precipitation of the secondary phases (mainly aluminium, niobium and titanium) are occurred between the temperature range of 600-700°C [3]. For a single-crystal superalloy, the recipe for the quenching process after solution treating generally done in the air. This process takes a lot of time when air is used as a quenching agent. For this reason, vacuum furnaces are using to reduce the quenching time by using pressurized argon or nitrogen. However, the process cost is very high when using vacuum furnaces. Here, molten salt quenching is an emerging technology that can be used in the secondary phase precipitation application after solution treating of the Ni-based superalloy. Molten salt baths are widely using in high temperature quenching applications such as martempering, austempering. In this process, the critical cooling rates of the material from 1150°C to 950°C and 950°C to 750°C are determined as 125°C/min and 120°C/min, respectively [1]. The important factors which have strong effect on the cooling rate of the steel are the oxidation level with the condition of the workpiece surface, geometric complexity and the mass of the workpiece with the agitation of the quenching medium [4]. In this paper, the cooling characteristics of the superalloy hollow disk is investigated under different molten salt bath temperatures. The temperature values of different locations on the hollow disk are measured in order to define the cooling rate. Then the numerical analysis is done to determine the heat transfer coefficient during the quenching process.

2. Materials and Methods

2.1 Material

The experimental work was conducted by using a Ni-based superalloy hollow disk as a workpiece. In order to record the workpiece temperature, two N-type thermocouples (TC) were mounted on the disk. The dimensions of the hollow disk and the TC locations is illustrated in Fig.1.

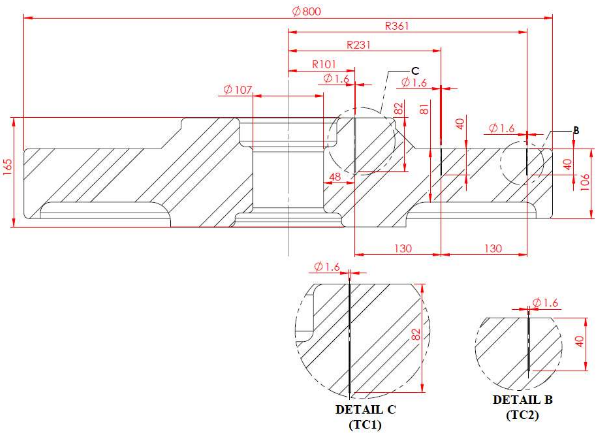

Figure 1. Test sample and thermocouple locations.

2.2. Experimental procedure

The experimental work was done by the facility that developed and manufactured by Sistem Teknik (Model no: BF-EH-A-100907-08) as shown in Fig.2.

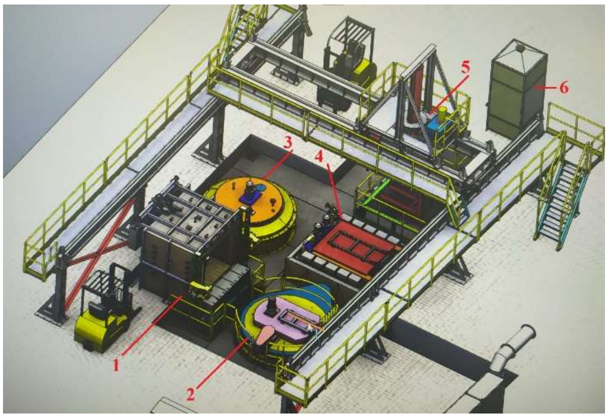

Figure 2. Experimental facility.

The facility consists of mainly six components and the numbers on the Fig.2 and Fig.3 represents;

- 1: Heating Furnace,
- 2: High temperature molten salt bath,
- 3: Low temperature molten salt bath,
- 4: Spare molten salt bath,
- 5: Manipulator and
- 6: Salt recovery unit.

In the experiments, the hollow disk was heated to 1150°C in 3 hours in the heating furnace. Then, it was discharged from the furnace and transferred to the high temperature molten salt bath which has a capacity of 5.7 m^3 via gripper mechanism. The transfer time of the hollow disk was kept as low as possible, between 5-10 s in order to minimize the heat losses through the atmosphere. On behalf of to improve the heat transfer between the molten salt and the hollow disk by agitation, two circulators were activated when the hollow disk is immersed to the tank. The cooling performance of the hollow disk inside the molten salt bath which has a rough composition like %50 NaNO3 and %50 KNO3 was obtained by recording TC1 and TC2 temperature values via datalogger.
The tests were conducted considering three different molten salt bath temperatures. The bath temperatures were selected as 300°C, 400°C and 500°C considering the maximum operation temperature of the molten salt [5].

2.3. Numerical procedure

Numerical analysis was done by using commercial simulation program Fluent to determine the heat transfer coefficients while the hollow disk is cooling in the molten salt bath. For this purpose, the geometry of the disk is imported to the program and the arbitrary heat transfer coefficient of the molten salt medium which was related with the literature was defined to the exterior boundaries of the geometry [4]. In order to determine the heat transfer coefficients, the inverse method was used as explained in the literature [2]. On the other hand, the evaluation of the actual heat transfer coefficient of the medium was determined by achieving the same temperature curve for each molten salt bath temperature as measured in the experiments.

3. Results and Discussion

Fig.3 shows the transportation of the heated hollow disk from the heating furnace to the high temperature salt bath during the experiments. The thermal image of the same position is given in Fig.4. From Fig.4, it can be seen that the maximum temperature is gathered from the hollow disk surface. This is meaningful when we considered the emissivity of the thermal camera is defined for the steel as 0,8 not for the ceramic fiber inside the heating furnace. This causes a lower temperature for ceramic fibres, thus the temperature value of inside the heating furnace seems lower than the workpiece.

Figure 3. Transportation of the hollow disk.

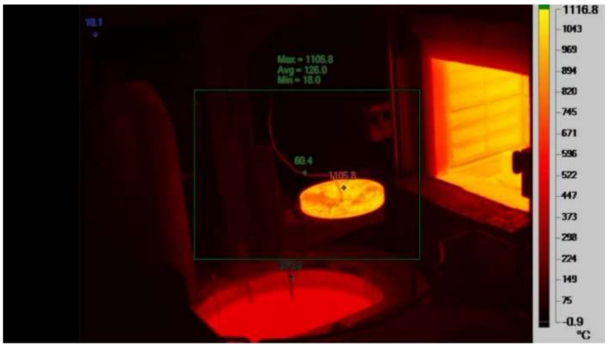

Figure 4. Thermal image of the transportation process.

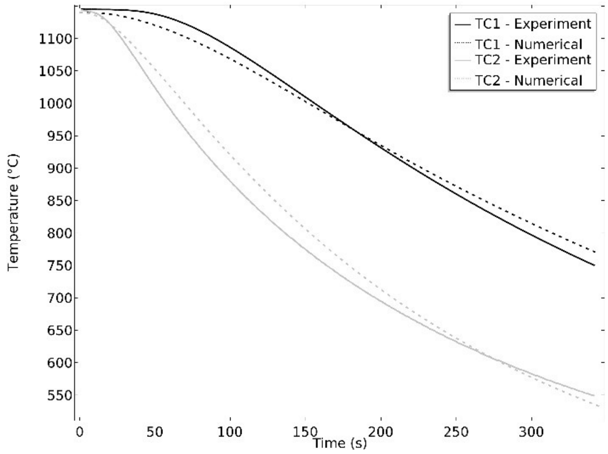

Figure 5. Time-temperature curves of workpiece for 300°C salt bath temperature.

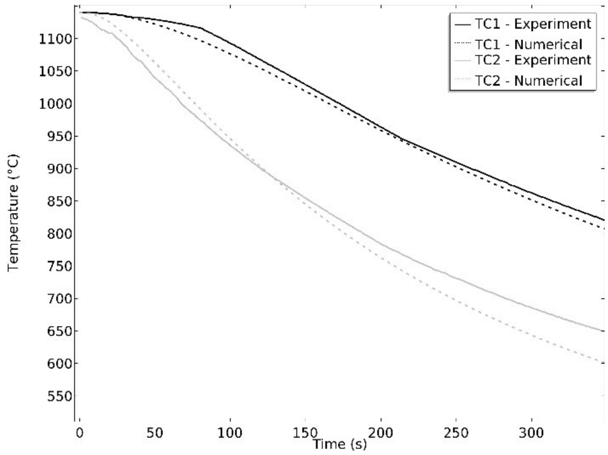

Figure 6. Time-temperature curves of workpiece for 400°C salt bath temperature.

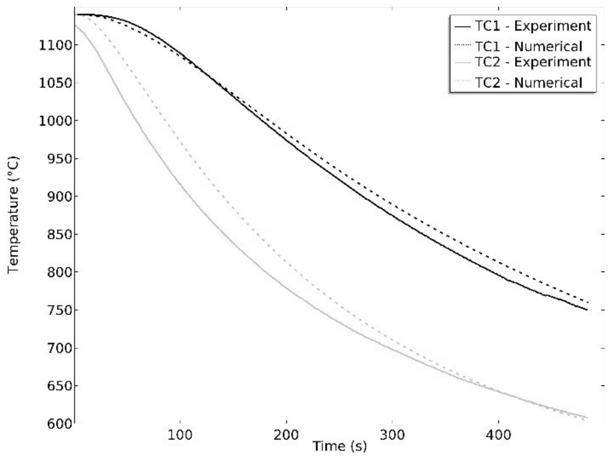

Figure 7. Time-temperature curves of workpiece for 500°C salt bath temperature.

Fig.5, Fig.6 and Fig.7 shows the temperature change of the workpiece under different salt bath temperature with regard to time elapsed. It can be seen from the Fig.5, Fig.6 and Fig.7 that the difference between experimental and numerical values are relatively close and it is in the acceptable limit for such applications.

For this work the heat transfer coefficient is evaluated as 650 W/m^{2}K regardless from the salt bath temperature. This indicates that the cooling rate of workpiece can be realized under different temperatures other than examined in the experiments.

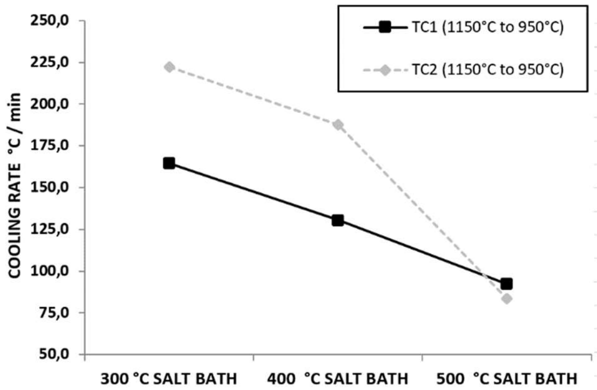

Figure 8. Cooling rate of workpiece between 1150°C to 950°C with changing salt bath temperature.

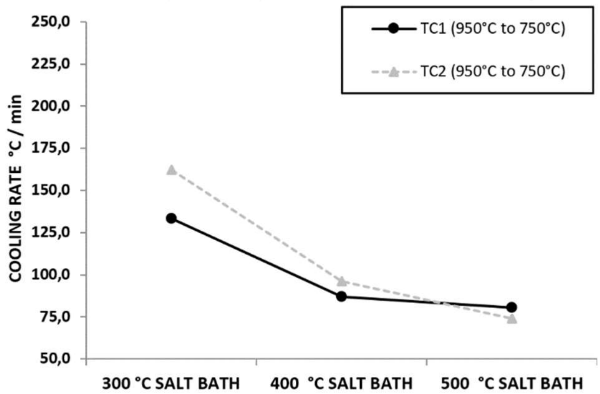

Figure 9. Cooling rate of workpiece between 1150°C to 950°C with changing salt bath temperature.

From Fig.8 and Fig.9, it can be seen that the cooling rate of the workpiece is decreasing against the increasing salt bath temperature. This is caused by the decreased temperature difference between workpiece and molten salt. On the other hand, the cooling rate difference between two locations on the workpiece also decreases with increasing temperature. This can be explained by the decreasing cooling effect of the salt bath. The convective heat transfer reduces with increasing salt bath temperature and it causes a relatively low cooling rate difference between two locations on the workpiece. The experimental work showed that the critical cooling rate could not be achieved when the molten salt temperature equals to 500°C. In order to make the heat treatment correctly, the molten salt temperature should be lower than that value.

4. Conclusion

In this work, the molten salt bath quenching of superalloy steel is investigated experimentally and numerically. The results showed that the cooling rate decreases with increasing salt bath temperature. It is found that the critical cooling rates to cool the material cannot be reached when the salt bath temperature is 500°C. Also, it is observed that the experimental and numerical values are in good agreement. From this point, the heat transfer coefficient evaluated as 650 W/ m^2K.

References

[1] M. J. Donachie, and S. J. Donachie, Superalloys a Technical Guide, ASM International, 2002, Ohio, USA.

[2] G. E. Totten, and J. Dossett, ASM Handbook Volume 4A:Steel Heat Treating Fundamentals and Processes, ASM International, 2014, Ohio, USA.

[3] J. R. Davis, Heat-Resistant Materials, 1997, ASM International, New York, USA.

[4] B. Liscic, H. M. Tensi, L. C. F. Canale, and G. E. Totten, Quenching Theory and Technology, 2010, CRC Press, Boca Raton, USA.

[5] E. Öztürk, and M. Yıldırım, Konya Journal of Engineering Science, 7 (2019) 604-611.