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Influencing on liquid quenching by surface structuring

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ABSTRACT

Quenching is an important process in the heat treatment of metallic components. This is usually performed as immersion quenching in vaporizing liquids, such as water. Quenching in water is characterized by relatively small effort and high average quenching rate. Disadvantage of this method is the occurrence of the Leidenfrost effect. The Leidenfrost effect manifests itself in the fact that a thin vapour film is formed on the hot component surface, which greatly reduces the heat flow between the component and the quenching medium. Depending on the component geometry and quenching conditions the vapour film collapses at different time and location. This causes component distortion and residual stresses. Many studies on the Leidenfrost effect are dealing with influences of quenching medium and quenching conditions. In this work, the influence of component surface structure on the quenching kinetic has been investigated as a novel approach. The focus of the work is on the investigation of surface structures, which can be produced during the turning process. The investigation was made in water by means of aluminium and steel components with defined groove surface structures. Geometry of the surface structure was varied. The evaluation was based on time-temperature measurements, and rewetting front observations. It was found that the purposefully structured surface can affect quenching kinetic considerably. The possibility to homogenize the quenching process by surface structuring adapted to component geometry was confirmed. This indicates a high potential for homogenizing of immersion quenching in vaporizing liquids.

1. Introduction

Heat treatment is one of the most important methods for tailoring of processing and functional properties of metallic components. In many heat treatment processes of metallic materials, for example martensitic hardening of steels or precipitation hardening of aluminium alloys, a rapid quenching has great importance. The aims of quenching are supersaturated solid solutions, which show high solid solution hardening or represent initial states for subsequent precipitation hardening. Quenching should be done as quickly as necessary to set the desired structures and properties. On the other hand it should be done as slowly and evenly as possible in order to reduce component distortion and residual stresses. Liquid quenching can be performed in very different media. For immersion quenching, evaporating liquids especially water or oil are mostly used. Immersion temperatures lay around 500 °C for aluminium alloys and around 800–1000 °C for steels. Advantages of quenching in baths with evaporating liquids are low cost and high average quenching rate. Disadvantage is the unevenness due to the Leidenfrost effect [1]. The Leidenfrost effect leads to the formation of a vapour film between hot component surface and quenching medium. The vapour film has an insulating effect and reduces the heat transfer. After reaching a certain temperature the vapour film collapses and nucleate boiling starts. The nucleate boiling causes a very high heat transfer. The collapse of the vapour film often occurs at different time and location. This is illustrated in Fig. 1 on the example of a metal cylinder quenched in water. In the first moment (t_0) after immersion of the hot cylinder in water, the entire surface is covered by vapour film (film boiling). Over time, the cylinder cools down and the vapour film collapses at the lower edge of cylinder (t_1). It forms a rewetting front which moves from bottom to the top of the cylinder. While the upper portions of the samples cool down relative slowly (film boiling), the lower portion of the sample cool down very quickly (nucleate boiling), see t_1 and t_2. At the end of quenching (t_3) the entire cylinder is completely under convection.

This time and location difference in the cooling rates along the cylinder can cause unevenness in microstructure as well as residual

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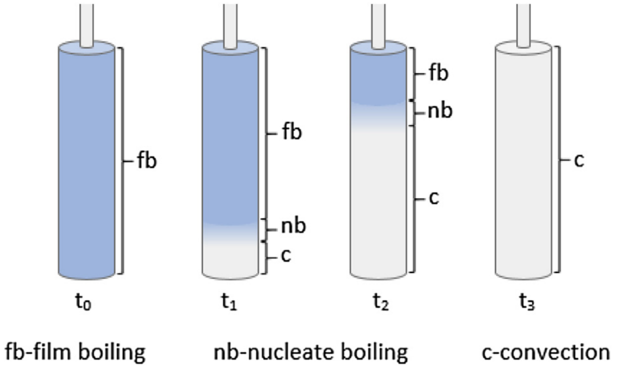

Fig. 1. Schematic illustration of quenching process in water.

stresses and component distortion. The Leidenfrost effect in evaporating liquids was very often studied and various approaches for reducing its influence exist. The approaches are, for example, high flow velocity of quenching medium [2,3], spray cooling [4–6], modifying of physical properties of quenching medium [7,8] and ultrasonic assisted quenching [9–11]. All these approaches concentrate on the quenching medium and quenching condition but not on the surface structure. The influence of sharp component edges is well known, which cool down faster and hence lead to an early local collapse of the vapour film [12]. The influence of surface structure depends on many parameters and therefore exhibits a complex behaviour. The dependence of Leidenfrost effect on roughness is ambiguous. Different roughness, material properties and the quenching conditions lead to different effects [13–16]. Thus, the increasing of roughness can reduce as well as encourage the Leidenfrost effect. E.g. the influence of surface roughness for single water droplets on horizontal copper discs was investigated [13]. The increase of the roughness from 0.1 to 1 μm prolongs the cooling time considerably. The further increase of the roughness to 3 μm shortens the cooling time (see also [20]). The assumption is that the irregularities on a surface can pierce the vapour film increasing the cooling rate or hinder the contact between cooling medium and sample surface, resulting in a reduced cooling rate.

In this work, the influence of the sample surface in combination with sharp and rounded sample edges on the Leidenfrost effect will be investigated. The focus of the investigation is on the influence of grooved surface structures, which can be manufactured during the turning process of cylindrical components without much additional effort. The idea is to destabilize the vapour film by means of the irregularities (groove tips) on the surface. Theoretically, sufficiently high grooves should pierce the vapour film (see Fig. 2) and shorten the film boiling phase.

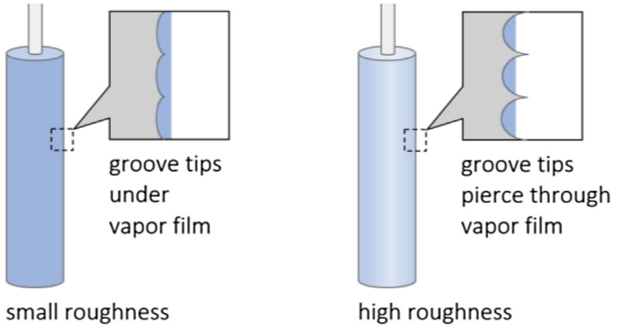

Fig. 2. Possible influence of groove depth on vapour film.

For that reason, experiments with different groove depths (roughness) are applied on aluminium and steel samples in order to derive the relationships between surface structures and quenching kinetics. Based on the obtained results, an attempt will be undertaken to homogenize the quenching process using grooved surface structures. For this purpose, samples with inhomogeneous surface structures will be used in order to control vapour film collapse by means of targeted surface structuring. In case of successfully targeted modulation of the Leidenfrost effect, the economics of manufacturing could be substantially increased. The post-processing of distorted components after quenching could be shortened or completely eliminated in the ideal case.

2. Materials and methods

2.1. Experimental setup

The experimental setup used in this work is illustrated in Fig. 3. The cylindrical sample is heated in a furnace to a determined temperature and after that quenched in the water tank. The water tank is a thermostat LAUDA PV 36 with an observation window and has a volume of 36 L. As quenching medium, tap water was used, which had been purified with activated charcoal filter. To immerse the sample into water, a semiautomatic kneeling system was used based on a guide rail and a brake unit. This allowed uniform and reproducible immersion of all samples in the quenching tank and the influence of uneven immersion could be minimized. After immersion, the distance from water surface to the upper end of sample is about 40 mm. The distance from the tank bottom to lower end of sample is about 110 mm.

As samples, cylinders with diameters of 29 mm and lengths of 120 mm were used. Cylinder materials of aluminium alloy EN AW-6082 (AlSi1MgMn) and austenitic stainless steel X5CrNi18-10 were investigated. This steel is not martensitic hardening, but it is a suitable model for martensitic hardening steels, because cooling curves can be recorded without superposition of transformation heat.

Samples with sharp and rounded edges were used (Fig. 4) since the geometry of sample edges has a great influence on quenching kinetic, especially on starting temperature of rewetting [1,18,19]. Curvature radii at the rounded samples are 14.5 mm on the bottom and 4 mm on the top of cylinders. For fastening on the sample

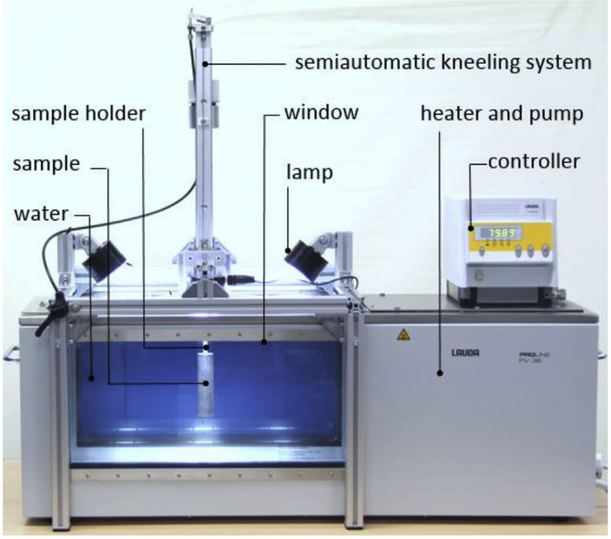

Fig. 3. Experimental setup.