Controlled spray quenching in heat treatment process

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Abstract

Spray quenching is a method for precise control of material and workpiece properties of metallic specimen in heat treatment processes. Specific material microstructure distributions in combination with the avoidance of workpiece distortion in heat treatment processes may be realized by impressing precisely controlled cooling with flexible flow fields based on multiple spray nozzle arrangements. This controlled liquid quenching by means of two-phase spray cooling enables the possibility to generate specific local heat transfer conditions on workpiece surfaces, which builds the basis for asymmetric quenching strategies for control of workpiece properties and reducing distortion.

The quenching process within heat treatment or hardening processes for specimen is a production step within the manufacturing procedure of metallic workpieces. The quenching process often is associated with geometric distortion of the specimen in the manufacturing process, which is activated by high temperature gradients and stress in the workpiece during the fast cooling process. In industrial practice, this specimen distortion is compensated by material allowance in the manufacturing and finishing rework after heat treatment process, respectively.

The asymmetric quenching process in heat treatment processes has originally been developed for gaseous flow processes. Here by local control of gas jet flows precise distribution of heat transfer rates can be established. However, the pure convective heat transfer with gaseous flows causes too low heat transfer rates for certain material classes and specimen sizes. When using liquid jets instead of quenching gas at high specimen surface temperatures a vapour layer formation on the heated workpiece surface occurs. For that reason spray of fine liquid and an overlaid gaseous flow is impinged on the heated surface. The impinging liquid fraction of the spray may be restricted so that on the specimen surface no liquid film with a vapour layer underneath is built. By means of spray cooling, the efficiency of a complete evaporative cooling process can ideally be reached. The use of two phase atomizers allows the adjustment of impressed heat transfer condition with the choice of spray parameters (liquid mass flow and gaseous pressure). For this reason, it is possible to set up local heat transfer conditions in ranges between pure gas and full liquid quenching processes.

This contribution describes the use of spray cooling techniques for specific quenching of simple shaped aluminum and steel specimen in heat treatment processes. For efficient estimation of the cooling process a spray characterization, consisting of drop velocity, drop diameter and impingement density measurements in combination with calculations of local heat transfer coefficients (HTC) is performed. The HTC-profile calculations were obtained from the solution of the inverse heat conduction problem based on thermographic temperature measurements during spray cooling of thin sheets. The used parameter range was a fluid volumetric flow rate of 0.25 l/h – 2.9 l/h and a gas pressure of 0.1 MPa – 0.56 MPa. The initial specimen temperature was about 1073 K and the detected surface temperature range reach from 1050 K - 400 K. Two experimental setups were used, the thermographic setup and a flexible spray field setup, as industrial used quenching setup. The estimated HTC have peak values of more than 6000 W/ (m²K) and depend on specimen surface temperature and position. The main parameter for the HTC distribution is the specimen surface temperature. The gas pressure influence on the cooling process is minimal. With an increasing flow the fluid flow exhibits a faster cooling reaction and a faster cooling of the specimen and therefor a higher HTC. Analysis of the cooling curves assumes a wide range HTC function and low range HTC function. Low range HTC function exhibits the influence of the Leidenfrost effect. Wide range HTC function demonstrated the function of temperature and position to the HTC. The temperature depending HTC distribution over the specimen surface also includes the non-directly impinged faces, which show the influence of the three dimensional heat conduction. The results are implemented and validated with established calculation, model approaches and numerical cooling simulations. Here the knowledge of HTC profiles for chosen spray operation parameters and the estimation of hardness measurements, process dependent resulting distortion and metallographic analysis build the basis for continuous analysis and validation of the cooling effect by asymmetric spray quenching of complex shaped workpieces.

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