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Simulation of structure and stresses during quenching of steel charges to minimise distortion

Keywords: Distortion, Quenching, Structure, Hardness, Simulation, Experiments

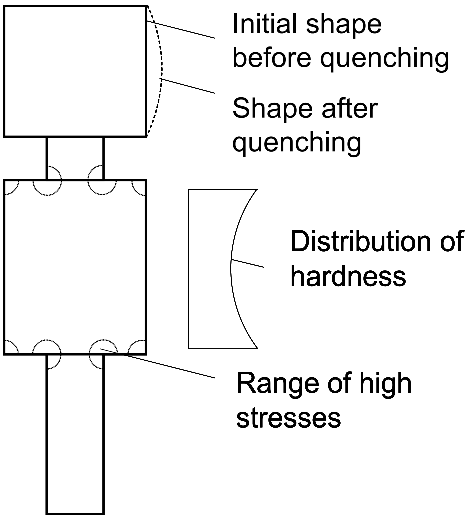


Fig. 1. Distortion and residual stresses after cooling, e.g. for hardening

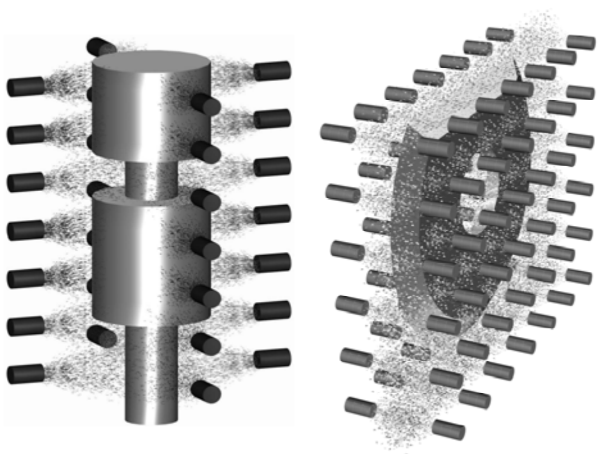
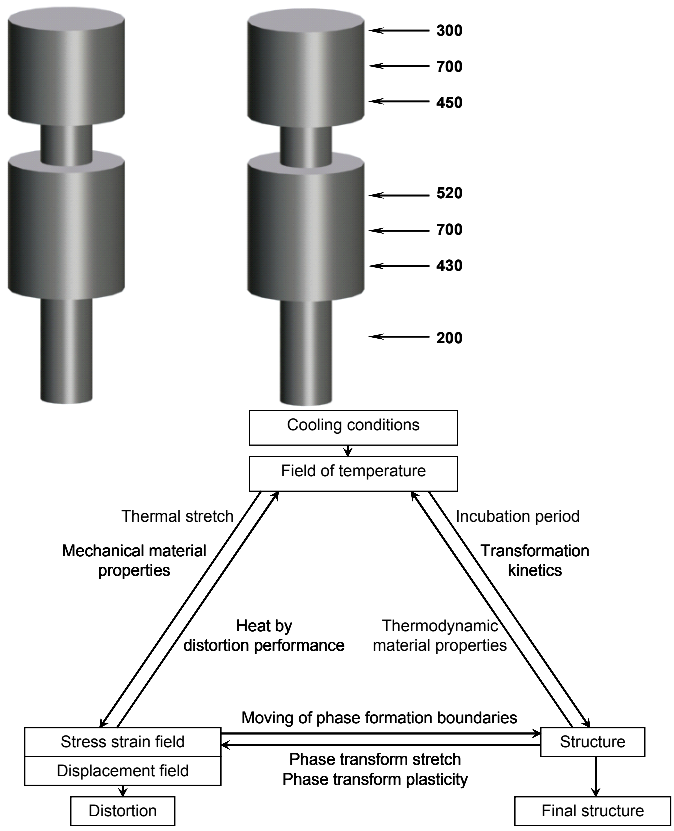
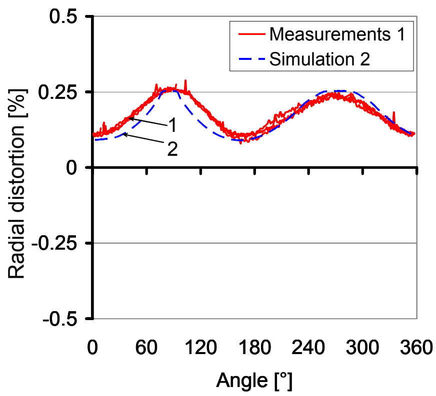


Fig. 2. The shaft and the disc with the field of nozzle.





	Small Shaft						Big Shaft					
	Perlite [%]		Bainite [%]		Martensite [%]		Perlite [%]		Bainite [%]		Martensite [%]	
	Mes.	Sim.	Mes.	Sim.	Mes.	Sim.	Mes.	Sim.	Mes.	Sim.	Mes.	Sim.
Point 1	0	0	33	31	67	69	94	86	0	5	6	9
Point 2	0	0	33	31	67	69	97	86	0	9	3	5
Point 3	0	0	22	18	78	82	100	87	0	15	0	0
Point 4	0	0	26	22	74	78	100	88	0	12	0	0

Fig. 3. Coupling and dependencies between the field parameters.

In most thermal treatment processes metals must be quenched after the heating process as example for hardness. But the quenching causes undesirable effects. A main problem is the distortion of the products. Other problems are the high residual stresses and an uneven distribution of the hardness on the surface (Fig. 1), as for example in hardening processes. For reducing the residual stresses of the products a following temper process is necessary. For reducing the distortion the products must be adjusted in special machines. These processes need considerable efforts.

What the reason for these problems? For hardening e. g. depending on size and design the metallic products are dipped into bathes of water, special oils, polymer solutions and so on, impinged with water by nozzles or poured with water. In these quenched methods the so called Leidenfrostproblem occurs. Over the surface forms a vapour film. Below the Leidenfrost temperature the vapour film collapses and nucleate boiling appears. Here the heat transfer is much higher than in film boiling. The problem is that the film collapses at edges, corners, roughness peaks or undefined positions at the surface. This results in big differences in quenching rate across the surface. It is impossible to influence the local heat transfer in these quenching processes. Products which need a nearly distortion free quenching must therefore be quenched in bathes consisting of liquid salt. Thus bathes are expensive because of efforts for environmental protection. As consequence research work of the last years tried to develop alternative quenching methods. To adjust the local heat transfer the quenching with air in an array of nozzles and the quenching with fine sprays of water to avoid liquid water films was researched. This research work deals with the possibilities of defined quenching in influencing the structure, the stresses and distortion. These properties were simulated mathematically for quenching processes to find optimised conditions. The fields of temperature, structure, stresses and strains must be calculated. All fields are coupled as described in Fig. 3. The temperature field is direct influenced by the quenching conditions and therewith indirect also the other two fields. This results in adjusting the structure and distortion.

The temperature field is solved with the Fourier differential equation. Here the material properties density, spec. heat capacity, conductivity and heat transformation enthalpy must be know until the range of high temperature. As boundary condition the heat transfer coefficient is given.

The formation kinetic of the structure is determined by the Johnson-Mehl-Avrami-equation. For the relation of stress and strain four different portions are to be taken into account for the strain rate tensor: the thermal transformation portion, the elastic portion, the plastic portion, and the phase transformation plastic portion.

The shaft and the disc with field of nozzles shown in Fig. 2 served as design typical for products in automobile industry are research here. The material is the steel 100Cr6 because its material values are well known.

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