Quenching of extruded profiles – finite element simulation as a tool to minimize profile distortion

I. Kniazkin, I. Kulakov, A. Shitikov: Micas Simulations Ltd; H.-W. Raedt: prosimalys GmbH

Role of quenching in profile extrusion

In profile extrusion, there are a number of output parameters that have to be considered closely in order to produce a competitive aluminium profile. These parameters are defined by tight requirements applied to the profiles and can be summarized as the absence of defects, acceptability of properties, conformity of dimensions to the tolerances, and productivity. The lack of defects and productivity are mostly defined by extrusion conditions, but the other characteristics can be affected by subsequent steps in extrusion production.

The majority of aluminium profiles are made from heat-treated aluminium alloys such as 2xxx, 4xxx, 6xxx and 7xxx series. This means that quenching and subsequent hardening by aging (natural or artificial) should be used in order to reach the required mechanical properties.

The most commonly used types of initial heat treatment are (1) quenching right after the profile comes out of the extrusion press and (2) post-process of cold profiles specially heated in furnaces and quenched in special water tanks.

For type (1), various quenching methods are currently available to cool down the profile once it leaves the press. There is a number of different systems available in the market that can provide different cooling environments: pressurized air, water mist or water spray. Each of these methods has its own advantages and disadvantages despite sharing the same goal. The application of fully automated puller systems provides unsurpassed capabilities in reducing profile twisting and significantly increases the efficiency of the entire process.

Quenching challenges

Once the profile leaves the press, the cooling rate starts to directly affect such parameters as strength, hardness and buckling. When the profile passes through the cooling system, the temperature of the profile is reduced to the ambient temperature. The cooling rate should be as high as possible in order to maintain the properties obtained during the extrusion process, and to prevent precipitation of alloying elements. However, it needs to be adjusted in order to avoid critical distortions of the profile in both cross-sectional and longitudinal directions considering the tolerances. Too rapid cooling may lead to large thermal stresses due to uneven temperature distribution, especially for profiles having a significant difference in wall thickness. The shape of the profile section itself can also affect the internal rigidity of the product and its deformation during quenching. That is why the proper setup of the cooling system is a very challenging task in industrial conditions.

To simplify this task, the QForm team has developed a brand-new module. This innovative approach allows the determination of the optimum cooling rate of the product, i.e., the required cooling intensity and the features of the cooling environment. This makes it possible to get the final product with a quenched structure and the required properties, together with a minimized distortion.

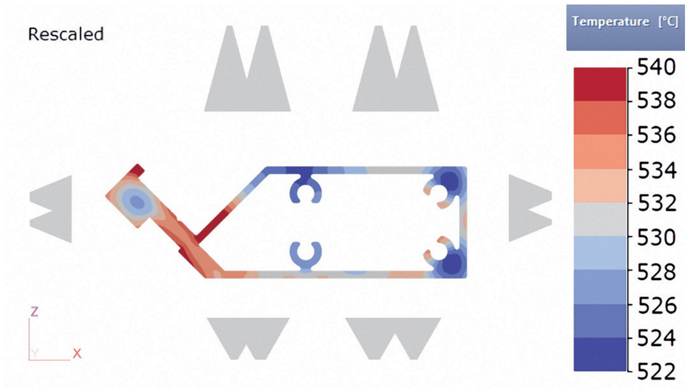

Fig. 1: Temperature distribution in the profile right after extrusion and position of spray nozzles

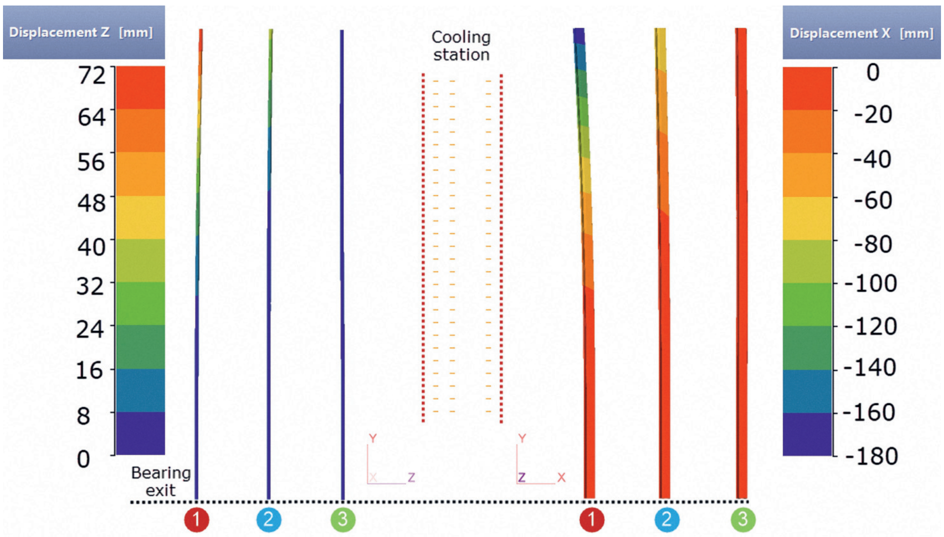

Fig. 2: Profile distortion during quenching with three different cooling modes

Profile distortion at quenching

In order to take the influence of the extrusion conditions on the quenching process into account, the temperature field as calculated in the extrusion simulation is taken as input data for the cooling operation (Fig. 1). This approach makes it possible to accurately calculate the temperature evolution at each particular zone of the profile, so that depending on the extrusion results the profile may react to the quenching differently. The spray nozzles are bodies that are positioned and directed in the 3D space around the extruded profile.

To demonstrate the influence of quenching conditions on the profile behaviour, three different cooling modes with various liquid pressures have been applied in the simulation as parameters of the water-spray system. For those modes, the deflection of the profile made of AA 6061 alloy was measured in two directions (Fig. 2).

It can be clearly seen that certain cooling regimes may lead to significant bending and twisting of the profile (Mode 1). This may lead to irreversible distortion of the profile in the form of waves. On the other hand, optimized cooling rates and other properly adjusted parameters of the quenching system can provide the straight balanced movement of the extrudate (Mode 3). The quantitative results representing profile distortion and twisting angle depending on the length of the extrudate are summarized as graphs (Fig. 3).

Puller setup

The puller is a special device that is used in an extrusion line with the main goal to prevent uncontrolled motion of the profile. One of the main settings of the puller is the velocity which is generally equal to the average exit velocity of the profile. It can be set to a velocity higher than the average exit speed in order to provide a stretching effect. This is especially useful in case of a significant profile distortion in the quench box (Fig. 4). Distortion and twisting can thus be eliminated even during the continuous extrusion process.

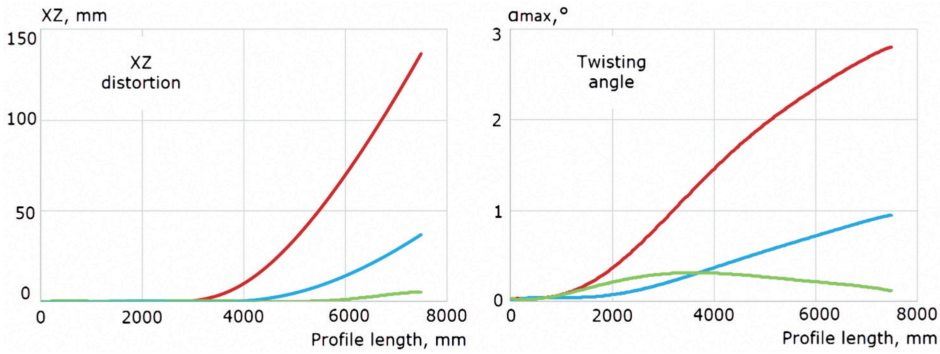

Fig. 3: Profile distortion and twisting angle depending on profile length. Colour codes see Fig. 2

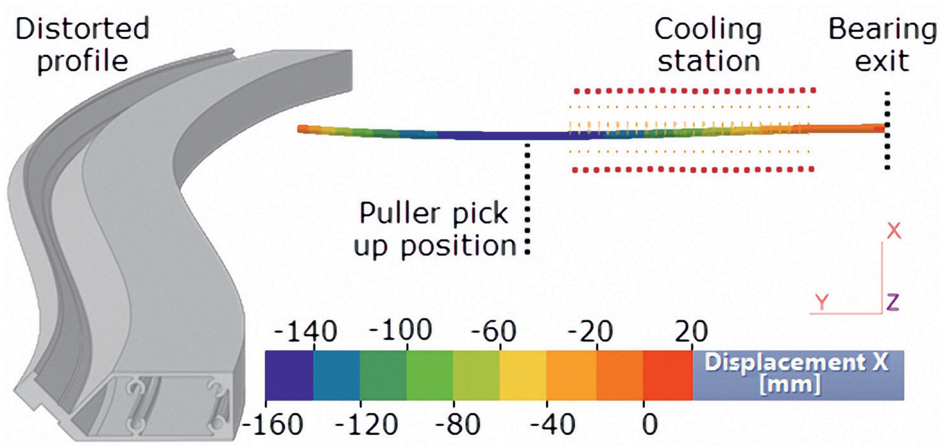

Fig. 4: Profile bending using puller with average profile velocity

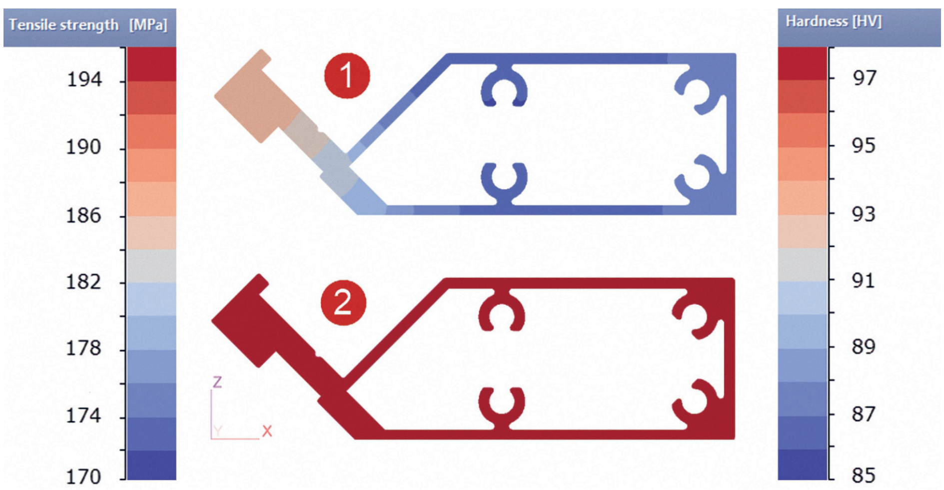

Fig. 5: Mechanical properties of the final product with different quenching conditions

Mechanical properties

In addition to the geometrical requirements for profiles, there is a number of demands for mechanical characteristics that determine the operational properties of the product. In general, these characteristics are tensile strength and hardness which are very sensitive to the regimes of heat treatment.

To demonstrate this influence, two different quenching modes were applied to the profile: natural air cooling without any special system and water-spray cooling. The results calculated with a hardness prediction model show that natural cooling with subsequent aging does not yield the best possible properties for this particular alloy (Fig. 5).

On the other hand, water quenching provides sufficient quenching speed to suppress high-temperature precipitation, thus obtaining maximum possible strength (2) after heat treatment. This means that quenching conditions in between these two modes can be potentially used in order to reach the required properties. This fits general practical recommendations for this alloy where fan air cooling is one of the commonly used methods.

Summary

Nowadays, tight demands on the profile extrusion process and on the subsequent operations require extremely high skills from engineers all along the entire production chain. The FEM-based simulation software QForm is now able to provide a comprehensive analysis of the whole production process: starting from tool design and extrusion itself and ending with the possibility to simulate profile behaviour during the quenching process including the prediction of mechanical properties of the final product. This makes it possible to design and optimize the whole technology in the virtual world (technology development 4.0). This leads to zero-trial projects (first time right) that significantly increase the on-time delivery (OTD) index and provide the user with decisive commercial benefits.

Authors

I. Kniazkin, I. Kulakov, A. Shitikov are with Micas Simulations Ltd., Oxford, UK. Contact: Kniazkin@QForm3d.com

H.-W. Raedt is with prosimalys GmbH, Bad Woerishofen, Germany. Contact: DrRaedt@prosimalys.de