THE MULTIDISCIPLINARY APPROACH TO THROUGH PROCESS MODELLING OF HOT FORMING COUPLED WITH MICROSTRUCTURE TRANSFORMATION

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SUMMARY

The formability of the metals as well as the service properties of manufactured parts significantly depend on the microstructure. During the series of hot forming technological operations, when manufacturing critical parts made of high strength alloys, the microstructure variation can be significant. Thus modelling of microstructure development through the whole process is becoming a very important issue in FEM simulation. However the attempts of using the physical models of microstructure transformation along with FEM code very often lead to unsatisfactory results. The main reason for this is the nature of many microstructural models. Being basically obtained from the almost isothermal experiments with constant strain-rate, they are normally well suitable either for steady deformation processes or for describing of some instantaneous relations. The real technological processes are highly inhomogeneous and have fast changing of temperature and strain-rate. This makes real situation to be far from a steady one. As the result, microstructure developed at each stage of the forming depends not only on the instantaneous conditions but also on the total thermo-mechanical history of deformation. This means that the model used for the description of microstructure transformation must have functional (history-dependent) nature and to be valid and stable in a wide range of main process parameters such as temperature and strain-rate.

Another specific feature of the hot forming processes is the high sensitivity of the mechanical properties of the material to its microstructural state. Any variation of microstructure causes change of mechanical behaviour of the material, e.g. coarsening of the grains normally leads to the hardening while refinement causes softening. This can significantly change the metal flow pattern. For proper description of the deformation of the material, concomitant microstructure transformation has to be taken into account by constitutive model included in FEM simulation.

1: Introduction

The microstructural state of the materials is very important for describing its mechanical behaviour, however majority of the phenomenological theories of plasticity manage to describe deformation processes quite accurately without direct involving any data related to the microstructure. This is possible because main information about material state is reflected partly in the mathematical structure of the constitutive equations, partly in material constants involved in them. Unfortunately in those cases when microstructure of the material undergoes active and significant transformation in the process of deformation this approach appears to be insufficient. The need of development and optimization of quite complicated technological processes calls for the ability of not only direct accounting of the microstructure development, but also of tracing it through the sequence of all technological operations along with their FEM simulation.

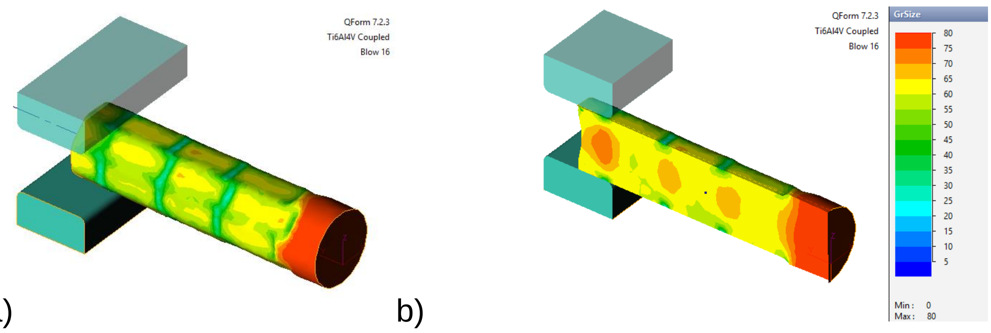
2: Description of the approach

This task represents an example of multidisciplinary problem. The methods of at least three branches have to be combined – material science, continuum mechanics and computational methods. Though these areas are quite close, matching them is sometimes not an easy task. Current paper presents one example of the phenomenological model with state variable characterizing microstructure suitable for the through process FEM simulation [1-3]. This model is developed for the two-phase $\alpha+\beta$ Titanium alloys similar to Ti-6Al-4V under hot deformation ($T>0.4T_m$). Single internal variable used in the constitutive equations is related with the effective grain size. Kinetics of this internal variable describes three main microstructural processes – static grain growth, deformation grain growth and refinement. The choice of the dominating mechanism depends on the current microstructural state and accumulated. In this way the kinetics of the internal variable has functional character – instantaneous response depends on the previous history that makes main constitutive model to be also history dependent.

The developed model is microstructurally coupled. It means that grain growth will cause hardening (increasing of the effective stress) and grain refinement – softening (decreasing of the effective stress). This is very important from the view point of the accuracy of the FEM simulation. Majority of technological processes are very non-uniform as well as corresponding microstructure development. This must be taken into account because sometimes localized hardening or softening can completely change the pattern of the material flow.

3: Examples of simulation

The model has been developed using programming facilities of QForm 7 FE metal forming simulation code [4]. Few examples of simulations illustrating these effects are presented in the paper. The first one is cogging of a cylindrical billet to reduce the grain size (Fig.1). We clearly see that the grain size reduction does not penetrate to deep inside the billet while near the surface we can observe the zones with very refined grains. The second example illustrates the deformation of bimetallic billet consisting of two pieces of the same material (alloy Ti6Al4V) but having different initial microstructure (Fig.2). The upper piece has ultrafine grain with average size 5 mkm while the lower piece has grain size 80 mkm. Using the same material model for both pieces but changing the initial grain size in them we have got in our simulation very different deformation patterns in both pieces. The piece with finer grain size subjects to larger deformation comparing to one with bigger grain size. It can be a good illustration of inverse Hall-Petch effect that takes place at high temperature.



a) b)

Figure 1: Grain size distribution in a billet after cogging in 16 blows. (a) surface, (b) crosscut. Material is Ti6Al4V alloy, initial temperature is 850 C, initial grain size 80 mkm

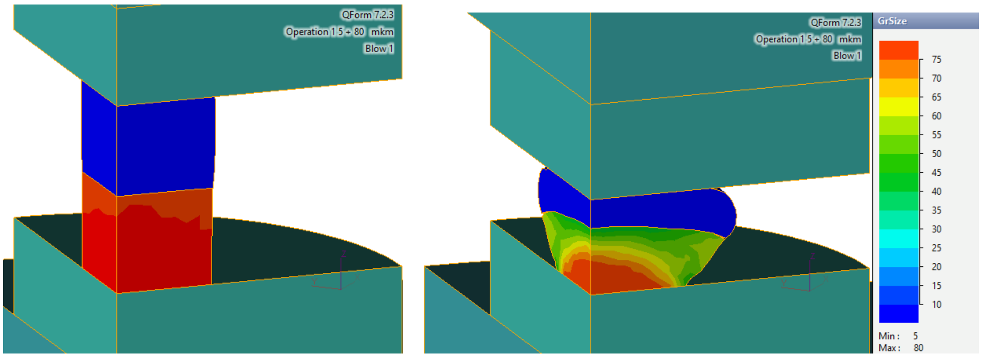


Figure 2: Grain size distribution and deformation of bimetallic billet. (a) Initial shape, (b) shape after upsetting by 50%. Material is Ti6Al4V alloy, initial temperature is 850 C, initial grain size 5 mkm (top) and 80 mkm (bottom)

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