MŰEGYETEM 1782

Budapest University of Technology and Economics
Faculty of Mechanical Engineering
Department of Applied Mechanics

Booklet of Thesis Statements

for the PhD dissertation

Constitutive modelling of compressible solids including viscoelastic-viscoplastic effects

Author:
Szabolcs BEREZVAI

Supervisor:
Dr. Attila KOSSA, associate professor

Submitted to
Géza Pattantyús-Ábrahám Doctoral School of Mechanical Engineering Sciences, Budapest University of Technology and Economics

Budapest, 2020

Overview of the dissertation

The mechanical behaviour of modern polymer materials exhibits different types of phenomena when exposed to normal loading such as creep, stress relaxation, yielding or plastic flow. The goal of the material characterisation (or constitutive modelling) process is to mathematically describe these phenomena and predict the material behaviour for complex load cases. There are two main modelling approaches that aim to capture the material response to external effects: microstructural and phenomenological approaches.

Microstructural (or micromechanical) models estimate the global mechanical behaviour using the knowledge about the local behaviour including interactions and deformation mechanisms from the atomic level in a monomer to the interaction of molecular chains in molecular level. Whereas the phenomenological modelling approach is mainly concerned with finding suitable mathematical relations between measurable macroscopic quantities (e.g. stress, strain, temperature, load-rate) based on experimental investigation focusing on the phenomena to be characterised. Although, these models are not capable of describing the microstructural deformation mechanisms underlying the macroscopic structure of the material.

The mechanical behaviour of polymers usually exhibits large strains and large deformations with highly nonlinear effects. Therefore, in general, finite strain (or large-strain) continuum mechanics description is required for the adoption of such behaviours. In addition to the nonlinear elastic contribution, the deformation may also show linear/nonlinear viscous and linear/nonlinear yielding properties. The available constitutive models (elastic, viscoelastic, viscoplastic) implemented in a commercial finite element (FE) software (such as Abaqus, Ansys, MSC Marc) can be effectively used to obtain very accurate numerical results for the deformation of metals even with finite strain formulation. These models certainly have limitations, but those are still widely accepted and applied by the engineering and academic community. However, it should be emphasised that general, accurate constitutive models for polymers with finite strain deformations in combination with viscoelastic and viscoplastic effects are not available, and hence, researchers usually develop their own models for the particular material under investigation. The commonly applied method for modelling the nonlinear viscoelastic-viscoplastic behaviour of polymers is the combination of a so-called hyperelastic constitutive equation with a suitably selected network of basic elements characterising nonlinear viscous and yielding behaviours. The hyperelastic modelling approach, was firstly developed for rubber-like materials, which are considered to be incompressible (or nearly-incompressible), and since then several incompressible hyperelastic models were published. However, several polymers show significant volumetric deformation, for which usually an additional term is introduced in the strain-energy potential. In the literature and in the commercial finite element software, the number of large-strain compressible hyperelastic material models are limited, while in the industry, there is significant need to model such material behaviour accurately.

This thesis is dedicated to the mechanical modelling of polymer materials where different aspects of viscoelastic and viscoplastic properties occur under finite strain deformations. Three fundamental constitutive modelling approaches are investigated and combined: compressible hyperelastic, viscoelastic and viscoplastic. The hyperelastic constitutive models are applied when the deformations are elastic but in a nonlinear manner with large strains. Viscoelastic approach is assumed when explicit time-dependence occurs in the governing equations and the material has strain-rate dependent behaviour or “memory effect” without permanent deformations. Finally, viscoplastic models are adopted for those materials where the yielding behaviour is also rate-dependent. In this thesis, all three kinds of modelling approaches are considered through examples related to real engineering application.

The thesis contributes to the state-of-the-art literature by developing material characterisation process including experimental, analytical, and numerical methods as well as by providing advanced constitutive models for open- and closed-cell foams, microcellular thermoplastic foams and polymer airsoft pellets. The mechanical characterisation of such materials is an actively researched field due to their widespread use and industrial importance. The primary motivation of the thesis was to develop such phenomenological models, parameter fitting algorithms and strategies that can efficiently be utilised in real engineering problems and forms also the basis for further research. A further aim of the thesis was analysing the applicability of the proposed phenomenological models and investigating the model prediction on complex load cases. With this aim, experimental validation methods were also developed and proposed.

Modelling approaches

The first investigated engineering problem is the pure elastic modelling of open- and closed-cell polymer foams using the Ogden–Hill compressible hyperelastic (or Hyperfoam) model. This model is well-known for foams and also implemented in ABAQUS, although, the material characterisation strongly depends on the transversal behaviour, which is usually neglected. Moreover, experimental investigations are also presented, including mechanical tests and image processing techniques, whereas constitutive modelling strategies are compared and new strategies are also proposed (*Thesis statement 1*).

The second topic is the rate-dependent behaviour of open-cell foams (so-called “memory foams”), for which a large-strain visco-hyperelastic constitutive model is proposed based on the previously applied Hyperfoam model. For this material model analytical stress solutions are derived (*Thesis statement 2*), that can be utilised in the parameter-fitting procedure, which significantly improves the fitting accuracy compared to the separated fitting approach. The benefits of the closed-form fitting method are also illustrated via a case study on memory foams applied in mattresses (*Thesis statement 3*).

The next engineering problem is the modelling of thermoplastic microcellular polyethylene-terephtelate foam material (MC-PET), which is applied in lighting applications and manufactured using thermoforming. In this case, the material behaviour, in addition to its elastic behaviour, also exhibits viscous properties, and the permanent deformation is also significant. Here, a parallel viscoelastic-viscoplastic model was proposed for characterising the material response on the entire temperature domain that is relevant from the thermoforming aspect (*Thesis statement 4*). For the parameter-fitting task, a FE-based numerical algorithm was implemented, whereas, for the validation, a punch-test based laser scanning method was proposed and the temperature dependency and sensitivity of material parameters are also analysed (*Thesis statement 5*).

Finally, he simulation of airsoft pellet impacts and its applicability as an impulse excitation method. This topic was motivated by the lack of proper excitation methods for rotating machine tools due to the posed safety-risks and the infeasibility of excitation by a modal hammer. The estimation of the relevant excitation frequency domain is determined based on numerical simulations. According to the mechanical tests, similar material behaviour was detected as in case of the MC-PET material. Thus the previous modelling approach was extended, and the applicability of pellet impacts was also demonstrated via an experimental case study and numerical simulations. (*Thesis statement 6*).

Thesis statement 1

I have analysed the purely elastic behaviour of polymer foams using the Ogden–Hill's compressible hyperelastic material model with particular interest on the lateral deformations. I have proposed an analytical Drucker-stability criterion for open-cell foams and I have performed detailed experimental analysis on a particular closed-cell polyethylene foam material including uniaxial, biaxial tests, and image processing. I have proposed two novel parameter-fitting strategies to simplify the uniaxial and to estimate the transverse biaxial stretches. By means of comparative analysis with the fitting procedure in ABAQUS, I have drawn the following conclusions.

A) Consider the N-th order Ogden–Hill's hyperelastic (Hyperfoam) constitutive model for a material (e.g. open-cell polymer foam) where the transverse deformations are negligibly small. Then, the assumption for the hyperelastic parameter $\beta_i = 0$ leads that the material meets the Drucker-stability criterion of $\mathrm{d}\boldsymbol{\tau} : \mathrm{d}\boldsymbol{h} > 0$, if and only if, the hyperelastic parameters μ_i and α_i satisfy

$$\sum_{i=1}^{N} \mu_i \lambda_k^{\alpha_i} > 0, \qquad k = 1, 2, 3$$

for all λ_k principal stretches corresponding to any arbitrary deformation.

B) During the parameter fitting of the Ogden–Hill's hyperelastic (Hyperfoam) model for closed-cell polymer foams with non-negligible transversal effects, let the approximation of λ_T^{UN} uniaxial transversal stretch characteristic be

$$\lambda_T^{\mathrm{UN}} = \lambda^{-\nu^*},$$

where ν^* is the generalized Poisson's ratio for finite strains, while λ is the logitudinal stretch. In this case, the unmea-

sured biaxial stretch characteristic (λ_T^{EB}) can be estimated from the uniaxial transverse stretch characteristic as

$$\lambda_T^{\mathrm{EB}} = 2\lambda_T^{\mathrm{UN}} + 1.$$

With this estimation, the accuracy of the parameter fitting can be significantly improved, when the optimization criterion is prescribed for both uniaxial and biaxial test data as

$$Q = Q_1^{\mathrm{UN}} + Q_T^{\mathrm{UN}} + Q_1^{\mathrm{EB}} + Q_T^{\mathrm{EB}},$$

in which Q_1^{UN} and Q_1^{EB} are the errors of the logitudinal stress predictions, while Q_T^{UN} and Q_T^{EB} ensure zero transverse stresses.

Related publications: [1],[2],[3]

Thesis statement 2

I have investigated the large-strain viscoelastic behaviour of polymer foams (memory foams) based on the visco-hyperelastic extension of the generalised Standard Solid Model in combination with Hyperfoam model. I have derived closed-form stress solution for ramp loading for confined homogeneous deformation and for open-cell foams, where the transverse effect is negligible. As a results the following thesis can be stated.

Consider Abaqus's finite strain visco-hyperelastic constitutive model in the form of

$$\boldsymbol{\tau}^D(t) = \boldsymbol{\tau}_0^D(t) - \mathrm{SYM}\left[\sum_{k=1}^{P} \frac{g_k}{\tau_k} \int_0^t \mathbf{F}_t^{-1}(t-s)\boldsymbol{\tau}_0^D(t-s)\mathbf{F}_t(t-s)\mathrm{e}^{-s/\tau_k}\mathbf{d}s\right],$$

$$\boldsymbol{\tau}^H(t) = \boldsymbol{\tau}_0^H(t) - \sum_{k=1}^{P} \frac{g_k}{\tau_k} \int_0^t \boldsymbol{\tau}_0^H(t-s)\mathrm{e}^{-s/\tau_k}\mathbf{d}s$$

where $\boldsymbol{\tau}^D$ and $\boldsymbol{\tau}^H$ are the deviatoric and hydrostatic Kirchhoff stresses, while g_k, τ_k are the Prony-parameters characterizing linear stress relaxation. When the instantaneous stress response $(\boldsymbol{\tau}_0^D, \boldsymbol{\tau}_0^H)$ is modelled using the Ogden–Hill's hyperelastic model, the τ_L longitudinal and τ_T transversal stress solutions for homogeneous confined compression ramp tests are expressed in closed-form as

$$\tau_L(t) = \begin{cases} \tau_{L0}(t) - \sum\limits_{k=1}^{P} g_k \left(\sum\limits_{i=1}^{N} \dfrac{2\mu_i}{\alpha_i} \eta_{ik} \right) & t \leq T, \\ \tau_{L0}(T) \left(1 - \sum\limits_{k=1}^{P} g_k \left(1 - \mathrm{e}^{\frac{T-t}{\tau_k}} \right) \right) - \sum\limits_{k=1}^{P} g_k \left(\sum\limits_{i=1}^{N} \dfrac{2\mu_i}{\alpha_i} \vartheta_{ik} \right) & t > T, \end{cases}$$

$$\tau_T(t) = \begin{cases} \tau_{T0}(t) - \sum\limits_{k=1}^{P} g_k \left(\sum\limits_{i=1}^{N} \dfrac{2\mu_i}{\alpha_i} \hat{\eta}_{ik} \right) & t \leq T, \\ \tau_{T0}(T) \left(1 - \sum\limits_{k=1}^{P} g_k \left(1 - \mathrm{e}^{\frac{T-t}{\tau_k}} \right) \right) - \sum\limits_{k=1}^{P} g_k \left(\sum\limits_{i=1}^{N} \dfrac{2\mu_i}{\alpha_i} \hat{\vartheta}_{ik} \right) & t > T, \end{cases}$$

where N and P denote the order of the Hyperfoam model and the Prony-series, T is the upload time, while $\Gamma[\nu, x]$ stands for the upper-incomplete Gamma-function. The quantities $\eta_{ik}, \vartheta_{ik}, \hat{\eta}_{ik}, \hat{\vartheta}_{ik}$ are the second-order parameter tensors, defined using the loading case parameter M as

$$\begin{aligned} \eta_{ik} =& \mathrm{e}^{\frac{-t-1/\dot{\varepsilon}}{\tau_k}} \left(\frac{-1}{\dot{\varepsilon}\tau_k} \right)^{M\alpha_i\beta_i} \left(\Gamma\left[1 - M\alpha_i\beta_i, \frac{-1}{\tau_k\dot{\varepsilon}}\right] - \Gamma\left[1 - M\alpha_i\beta_i, \frac{-1 - t\dot{\varepsilon}}{\tau_k\dot{\varepsilon}}\right] \right) \\ &+ \mathrm{e}^{-\frac{t+1/\dot{\varepsilon}}{\tau_k}} \left(\frac{-1}{\dot{\varepsilon}\tau_k} \right)^{-\alpha_i} \left(\Gamma\left[1 + \alpha_i, -\frac{1 + t\dot{\varepsilon}}{\tau_k\dot{\varepsilon}}\right] - \Gamma\left[1 + \alpha_i, -\frac{1}{\tau_k\dot{\varepsilon}}\right] \right), \end{aligned}$$

$$\begin{aligned} \vartheta_{ik} =& \mathrm{e}^{\frac{-t-1/\dot{\varepsilon}}{\tau_k}} \left(\frac{-1}{\dot{\varepsilon}\tau_k} \right)^{M\alpha_i\beta_i} \left(\Gamma\left[1 - M\alpha_i\beta_i, \frac{-1}{\tau_k\dot{\varepsilon}}\right] - \Gamma\left[1 - M\alpha_i\beta_i, \frac{-1 - T\dot{\varepsilon}}{\tau_k\dot{\varepsilon}}\right] \right) + \\ &+ \mathrm{e}^{\frac{-1-\dot{\varepsilon}t}{\dot{\varepsilon}\tau_k}} \left(\frac{-1}{\dot{\varepsilon}\tau_k} \right)^{-\alpha_i} \left(\Gamma\left[1 + \alpha_i, \frac{-1 - T\dot{\varepsilon}}{\tau_k\dot{\varepsilon}}\right] - \Gamma\left[1 + \alpha_i, \frac{-1}{\tau_k\dot{\varepsilon}}\right] \right), \end{aligned}$$

$$\hat{\eta}_{ik} = \mathrm{e}^{\frac{-t-1/\dot{\varepsilon}}{\tau_k}} \left(\frac{-1}{\dot{\varepsilon}\tau_k}\right)^{M\alpha_i\beta_i} \left(\Gamma\left[1-M\alpha_i\beta_i, \frac{-1}{\tau_k\dot{\varepsilon}}\right] - \Gamma\left[1-M\alpha_i\beta_i, \frac{-1-t\dot{\varepsilon}}{\tau_k\dot{\varepsilon}}\right]\right) + 1 - \mathrm{e}^{\frac{-t}{\tau_k}},$$

$$\hat{\vartheta}_{ik} = \mathrm{e}^{\frac{-t-1/\dot{\varepsilon}}{\tau_k}} \left(\frac{-1}{\dot{\varepsilon}\tau_k}\right)^{M\alpha_i\beta_i} \left(\Gamma\left[1-M\alpha_i\beta_i, \frac{-1}{\tau_k\dot{\varepsilon}}\right] - \Gamma\left[1-M\alpha_i\beta_i, \frac{-1-t\dot{\varepsilon}}{\tau_k\dot{\varepsilon}}\right]\right) + \mathrm{e}^{-\frac{t-T}{\tau_k}} - \mathrm{e}^{\frac{-t}{\tau_k}}.$$

Related publications: [1],[4],[5],[6]

Thesis statement 3

I have demonstrated, that the closed-form stress solution can be effectively utilised in the material characterisation process via the detailed experimental case study of an open-cell memory foam. By comparing the results with the separated fitting approaches in the literature, I have obtained the following results.

Consider the parameter fitting of open-cell polyethylene memory foams with significant viscoelastic effects and negligible transverse deformation (i.e. $\beta_i = 0$) using Abaqus's finite strain visco-hyperelastic constitutive model in combination with the Ogden–Hill's hyperelastic model. In this fitting process, the $2N$ Hyperfoam and $2P$ Prony-parameter of can be fitted in one step to the uniaxial stress relaxation test (ramp test) with excellent accuracy ($R^2 > 0.98$) using the closed-form stress solution for ramp test, compared to the separated fitting approaches (e.g. Zapas-Phillips, Factor-of-ten, Solvari-Malinen methods), which contain significant error due to the idealisation of ramp test.

Related publications: [1],[4],[5],[6]

Thesis statement 4

I have performed detailed experimental study on the mechanical behaviour of a particular microcellular polyethene-therephtalate foam material on wide temperature range. I have proposed a parallel viscoelastic-viscoplastic model, that is able to characterise the material on the entire temperature regime with excellent accuracy. Furthermore, I have also proposed a punch-test based validation technique for the validation of the fitted model non-homogeneous deformation with complex geometry. By analysing the performance of the proposed models, I have obtained the following results.

The mechanical behaviour of thermoplastic microcellular polyethene-therephtalate foam material shows significant elastic, rate-dependent and permanent deformations on the temperature domain of 21–210 °C, which is relevant for its thermoforming applications.

The captured mechanical behaviour can be effectively modelled on the entire temperature domain using a parallel viscoelastic-viscoplastic constitutive model with finite strain approach, where the viscoelastic properties modelled via a Maxwell-element with nonlinear power-law creeping law with strain- and time-hardening, while the yielding behaviour is modelled with associative flow rule based on the von Mises yield criterion with linear isotropic hardening. At high temperatures, however, the sensitivity of the model increases significantly.

The accuracy of time- and strain-hardening power-law creep laws shows only minor discrepancy in uniaxial case, and furthermore the constitutive model also predicts the force-displacement characteristic of punch-tests within reasonable errors.

Related publications: [7],[8],[9],[10]

Thesis statement 5

I have performed the constitutive modelling of a particular microcellular polyethene-therephtalate foam material on wide temperature range. Using a FE-based fitting procedure I have determined the temperature dependent material parameters corresponding to the parallel viscoelastic-viscoplastic material model. By means of the analysis of the parameters I have proposed analytical functions, that describe the variation of parameters with the temperature.

Consider the temperature-dependent mechanical behaviour of the microcellular polyethene-therephtalate foam to be modelled using the parallel viscoelastic-viscoplastic constitutive model as a combination of an elastic-plastic network based on von Mises yield criterion with linear isotropic hardening and a Maxwell-element with nonlinear strain and time hardening power-law creeping. The temperature-dependency of the material parameters, namely the elastic modulus (E), initial yield stress (σ_{y0}), hardening modulus (H), fraction of elasticity (f_e), creep-law coefficient (A) and exponents (m, n), can be characterized with monotonous, continuous functions of the T actual temperature and T_g glass-transition temperature in the form of

$$E(T) = E_1 \arctan\left(E_2\left(T - T_g\right)\right) + E_3,$$
$$H(T) = H_1 \arctan\left(H_2\left(T - T_g\right)\right) + H_3,$$
$$n(T) = n_1 \arctan\left(n_2\left(T - T_g + n_3\right)\right) + n_4,$$
$$m(T) = m_1 \arctan\left(m_2\left(T - T_g + m_3\right)\right) + m_4,$$
$$\sigma_{y0}(T) = \begin{cases} Y_2\left(T - T_g\right)^2 + Y_1\left(T - T_g\right) + Y_0, & T \leq T_g \\ Y_3\left(T - T_g\right) + Y_0, & T > T_g \end{cases},$$
$$A(T) = \begin{cases} A_1\left(T - T_g\right) + A_0, & T \leq T_g \\ A_3\left(T - T_g\right)^2 + A_2\left(T - T_g\right) + A_0, & T > T_g \end{cases}, \qquad \text{and}$$

$$f_e(T) = \begin{cases} f_{e1}\,(T - T_g) + f_{e0}, & T \leq T_g \\ f_{e2}\,(T - T_g) + f_{e0}, & T > T_g \end{cases}.$$

Related publications: [7],[8],[10]

Thesis statement 6

I have investigated the material behaviour of airsoft pellets using quasi-static experimental work and I have revealed that the material shows viscous-elastic-plastic properties. For the explicit dynamic simulation of pellet impacts I have introduced the elastic-plastic boundary models corresponding to instantaneous and long-term loadings. For the validation of the material model I have performed high-speed camera measurements and a case study of impulse excitation. By comparing the performance of the airsoft pellet impact with modal hammer excitations, I have drawn the following conclusions.

During the impact of polymer airsoft pellets applied for impulse excitation, the mechanical behaviour exhibits viscous-elastic-plastic properties, which can effectively be modelled by the parallel viscoelastic-viscoplastic constitutive model. The contact characteristics can be determined by explicit dynamic finite element simulations using the elastic-plastic boundary models of the constitutive equation, corresponding to the instantaneous and long-term limit cases. The applicability limit of the airsoft pellet as an impulse excitation can be determined by the relevant frequency ${}^{rel}f$ introduced as the highest frequency f, for which

$$\log|\Phi_{rel}(\omega)| > -1.5,$$

holds for all $\omega \in [0, 2\pi f]$, in which

$$\Phi_{rel}(\omega) = \frac{|\Phi(\omega)|}{\max\limits_{\omega \geq 0} |\Phi(\omega)|},$$

is the impact force spectra. This method ensured optimal excitation up to 24 kHz for HIPS pellet, which is significantly better than the limit of classical modal hammer excitation with rubber, polymer or metal hammer tips. By increasing the impact speed v, the relevant frequency bandwidth shows monotonously increasing characteristic according to

$$^{rel}f(v) = c_2 v + c_1\sqrt{v} + c_0,$$

where constants c_0, c_1 and c_2 can be determined experimentally for different pellets.

Related publications: [11],[12],[13],[14]

Bibliography

[1] S. Berezvai and A. Kossa. Closed-form solution of the Ogden–Hill's compressible hyperelastic model for ramp loading. *Mechanics of Time-Dependent Materials*, 21(2):263–286, 2016.

[2] S. Berezvai and A. Kossa. Effect of the skin layer on the overall behavior of closed-cell polyethylene foam sheets. *Journal of Cellular Plastics*, 52(2):215–229, 2015.

[3] A. Kossa and S. Berezvai. Novel strategy for the hyperelastic parameter fitting procedure of polymer foam materials. *Polymer Testing*, 53:149–155, 2016.

[4] A. Kossa and S. Berezvai. Visco-hyperelastic characterization of polymeric foam materials. *Materials Today: Proceedings*, 3(4):1003–1008, 2016.

[5] S. Berezvai and A. Kossa. Memóriahabok mechanikai modellezése. *XXIV. Nemzetközi Gépészeti Találkozó, Déva, Románia*, pages 47–50, 2006.

[6] S. Berezvai and A. Kossa. Nonlinear viscoelastic characterization of polymeric foams. *Proceedings of the VII European Congress on Computational Methods in Applied Sciences and Engineering*, 2016.

[7] S. Berezvai and A. Kossa. Performance of a parallel viscoelastic-viscoplastic model for a microcellular thermoplastic foam on wide temperature range. *Polymer Testing*, 84:106395, 2020.

[8] S. Berezvai and A. Kossa. Characterization of a thermoplastic foam material with the two-layer viscoplastic model. *Materials Today: Proceedings*, 4(5):5749–5754, 2017.

[9] S. Berezvai, A. Kossa, and A. K. Kiss. Validation method for thickness variation of thermoplastic microcellular foams using punch-tests. *Materials Today: Proceedings*, 2020.

[10] S. Berezvai and A. Kossa. Viszkózus-rugalmas-képlékeny anyagmodellek vizsgálata mikrocellás polimer hab hőformázása esetén. *XIII. Magyar Mechanikai Konferencia, Miskolc*, 2019.

[11] S. Berezvai, A. Kossa, D. Bachrathy, and G. Stepan. Numerical and experimental investigation of the applicability of pellet impacts for impulse excitation. *International Journal of Impact Engineering*, 115:19–31, 2018.

[12] S. Berezvai, A. Kossa, and G. Stepan. Airsoft lövedék viszkózus-rugalmas-képlékeny ütközésének szimulációja és alkalmazása. *XXVI. Nemzetközi Gépészeti Konferencia, Marosvásárhely, Románia*, pages 39–42, 2018.

[13] S. Berezvai, A. Kossa, and G. Stepan. Nonlinear material modelling of an airsoft pellet applied for impulse excitation. *European Nonlinear Oscillations Conference, Budapest, Hungary*, 2017.

[14] S. Berezvai, A. Kossa, and G. Stepan. Investigation of the performance of the two-layer viscoplastic model applied for simulating airsoft ball impacts. *Computational Plasticity Conference, Barcelona, Spain*, 2017.

Categorisation of publications

Journal publications: [1], [2], [3], [7], [11]

Conference proceedings: [4], [8], [9]

Conference proceedings in Hungarian: [5], [12]

Conference abstracts: [6], [13], [14]

Conference abstracts in Hungarian: [10]