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Review paper

MODEL OF ROCK MELT PENETRATION INTO IN RADIAL FRACTURES EVOLVED UNDER HIGH PRESSURE AND TEMPERATURE CONDITIONS

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Abstract: Deep deposit extractions require research in new technologies of mineral resource search and exploitation. Thermal contactless methods give good opportunity to drill relatively great depths. According to findings of theoretical and practical studies, radial fractures evolve in thermally strained rock environ. Therefore, for the new drilling method research, it is necessary to study both drilled rock and resulting melt in detail. This paper deals with rock melt and its possible penetration into fractures formed during drilling process. Simultaneous recording of TG and DTA using thermoanalyzer SETARAM TGTDA92 was made to determine phase transitions and rock melting temperatures. Using ANSYS13 software, it was possible to create CAD model and to determine the behavior of melted rock and rock melt. The results of the study are meant for their practical use during the vertical drilling processes.

Key words: rock, melt, penetration, radial fracture, deep drilling

1. INTRODUCTION

Research in new methods (Lazar et al. 1998; Rybár et al. 2004) of deep lying deposit extractions requires deep theoretical and practical knowledge of mineral, rock and rock massif features under conditions of high pressure and temperature. The reason is, inter alia, the fact that existing technologies of deep drilling are theoretically and practically limited in the range (or depth). Based on present research, new Technologies with deeper range need contactless methods (no contact of drilling tool with the rock). They can be based on thermal methods, e.g. drilling by hydrogen flame. Viscosity measuring of melted rock in temperature interval from 1200°C to 1600°C is difficult process. Therefore, mathematical-physical model from the environment of computer fluid dynamics (CFD) is used to simulate real process. Input data for simulation are obtained from results of experiments dealing with physical properties of materials.

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2. THE RANGE OF MELT PENETRATION INTO RADIAL FRACTURES AROUND THERMALLY STRAINED ROCK

Interaction of rock and hydrogen flame results in formation of rock melt and steam as a secondary product of hydrogen combustion. Theoretical and practical studies show that, under conditions of high pressures and temperatures, radial fractures form in environs of thermally strained rock. To create radial fractures around drilled hole, it is necessary to overcome the tensile strength of the massif's rocks. For example, it is sufficient to reach 0.44 to 0.75 times the geostatic pressure for hydraulic fracturing of rocks during hydrocarbon exploration. Hydrostatic fracturing of surrounding rock of drill hole Stretava was reached at the value of 0.83 times the geostatic pressure (Sekula et al., 1999). The range of radial fractures can reach 30 to 50 times the drill hole diameter.

Viscosity of melted rock and dynamics of rock melting process and pressure increase allows to impress and to absorb melted rock into radial fractures.

3. THERMOANALYTICAL STUDY OF THE SAMPLES

Simultaneous measures of TG and DTA using thermoanalyzer SETARAM TGDTA92T were performed to detect:

- phase transitions and
- rock melting temperature.

Rock samples were studied in thermal interval 20–1450°C at heating speed 10°C·min^{-1}. The amount of studied powdery samples varied from 30 to 60 mg. Air with flow rate of 60 ml·min^{-1} was used as a working gas.

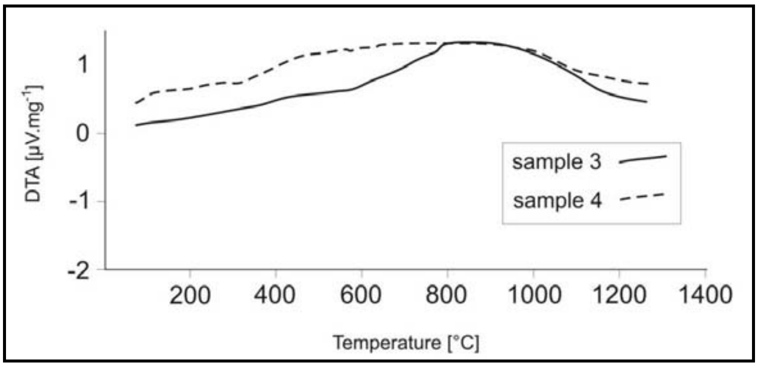

Figure 1 - DTA record of andesite sample, pike positions refer to pikes of derivated thermogravimetric signal

Differential thermal analysis (DTA) is based on measuring of small temperature differences at steady heating of sample and reference (Figure 1), usually inert matter which are placed in analyzer oven so that the heating conditions are the same. Differences between sample temperature and inert matter sample measured by thermocouples, in this case Pt-PtRh, indicate changes in the sample enthalpy based on the temperature. Phase transitions of the first type present as pikes with size proportional to share of active component in the sample. Analyzer SETARAM TGDTA92 is able to measure weight changes mainly connected to thermal disintegration of studied sample (TG-Thermogravimetry). It is possible to determine the part of weight decrease.

From the weight decrease, it is possible to determine share of the component which was thermally disintegrated producing gaseous products which decreased sample weight. Derivation of the signal (DTG) gives better information about disintegration speed. It is similar dependence like enthalpy change at speed change.

Impact of high temperatures on the rock causes different effects which also depend on place and time of temperature affect. "Thermal shock" (means immediate impact of very high temperatures on heterogeneous elements of surrounding rock) causes various thermal stresses around thermal source what results from different coefficients of linear thermal expansion of minerals building directly surrounding rock. Local thermal stresses can expand into irreversible deformation and growth of tense stresses and expansion of emerging rudiments of fractures and rapidly emerging radial fractures across the rock (Figure 2).

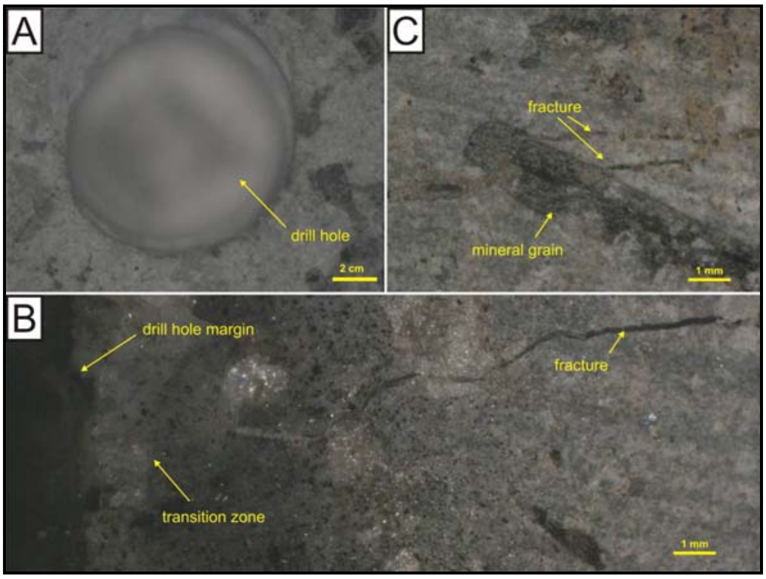

Figure 2 - (A) drilled hole in the andesite rock, (B) detail of drill hole margin with visible radial fracture, (C) detail of mineral grain dividing originally one radial fracture into two

Extremely high temperatures can also cause another effect – formation of melt rock smelting from original mother rock (Figure 3 and 4).

Figure 3 - (A) Original andesite rock sample, (B) resulting melt from mother rock

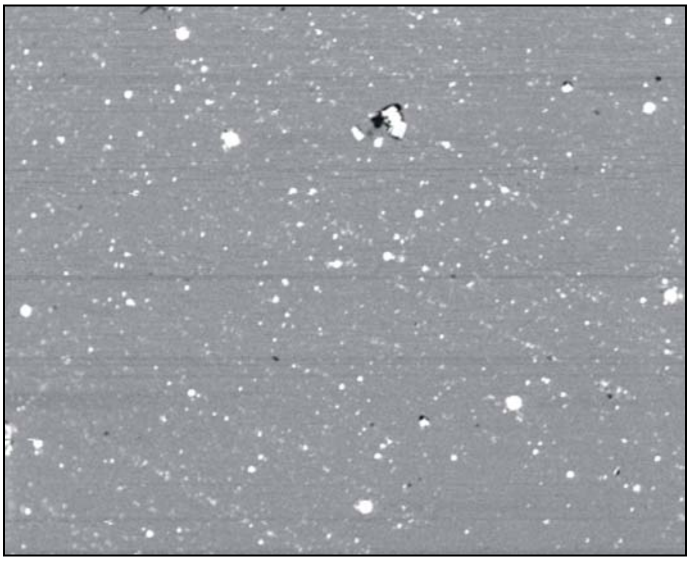

Figure 4 - Andesite melt, zoom: 86x

At progressive heating of rock during longer period of time, the rock can be strain hardened at first when dislocations, which group, mutually interact, concentrate along grain borders etc., form and move. Further temperature increase results into opposite effect - forming of microfracture rudiments with gradual decrease of rock strength.

From a place of high temperature activity point of view (e.g. on block sample of andesite), pieces of rock sputter due to the low and irregular thermal conductivity of elements comprising surface layers of the rock without desired penetration of the flame into the rock sample and its melting. Development of the heat diffuse within andesite block is visible on thermal records after few minutes flame activity with temperature over 1200°C.

Change of andesite block shape resulting from the temperature increase shows that melting process of the sample starts at 1300°C (Figure 5). Melt temperature was determined based on the norm DIN 51730.

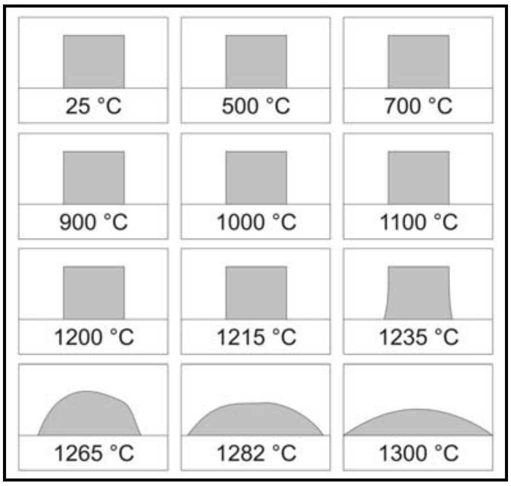

Figure 5 - Course of the andesite block melting process (Rybár et al. 2004)

4. ANDESITE MELT CHARACTERISTICS

After the sample melt at 1660°C, black compact amorphous matter locally with porous vesicular texture formed (Figure 5). Maximal dimensions of spherical and oval pores reach 0.6 cm in diameter. Based on microscopic study, hyaline structure with poorly visible wavy stripes, which originated due to fluid flow of the glass material, was identified.

From diffractive record of the melt (Figure 6) it can be assumed that almost whole sample is amorphous. In part between 20 to 35 *2 theta* it is possible to see diffractions of non-melted microcrystals.

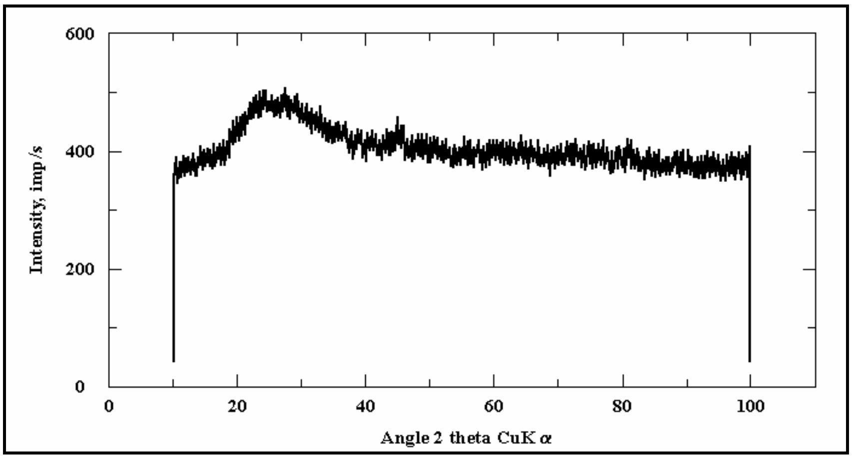

Figure 6 - Diffractive record of andesite melt

5. MELT PENETRATION MODEL

To verify the prediction about melt flow and its cooling in formed fractures, numerical simulation of flow was realized. The simulation was realized using ANSYS13 software.

CAD (computed aided design) model of flow physical environment with cylindrical entrance (diameter 30 mm and three levels with 25 mm spacing and 0.4 mm long gaps) was created. Numerical solution of CFD (computational fluid dynamics) equations requires that physical environment, where the flow is computed, has to be discretized. It means that the environment is covered by the point grid. In our study, we used non structured grid consisting of hexydral and prismatic elements with number of 2M. Initial model pressure was 1 MPa, density of the model melt changed depending on temperature according to the formula $6.358 - 0.0292T + 0.00004T^2$. Specific heat 2700 $J \cdot kg^{-1} \cdot K^{-1}$, thermal conductivity 0.25 $W \cdot m^{-1} \cdot K^{-1}$ and viscosity were functions of temperature according to the formula $0.00065 + 0.000025T$. Temperature of modeled melt was 360°K. Simulation was solved stationary. Impact of gravitation was included.

The result of modeling is modeled melt temperature layout within modeled environment. Minimal temperature changes compared to the ambient temperature are in the corners, where modeled melt gets into solid state (Figure 7).

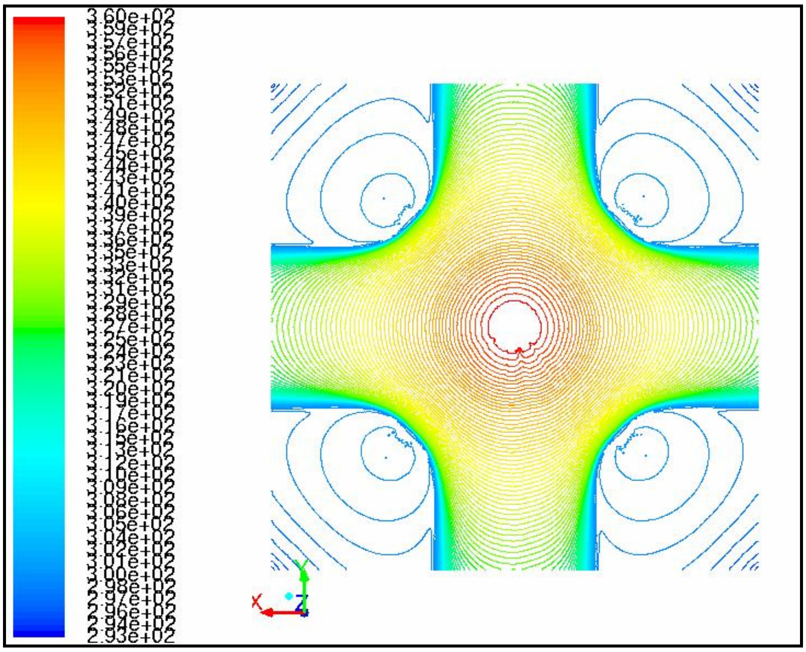

Figure 7 - Temperature distribution in upper part of the model

Modeled melt solidification in the space describes the distribution of liquid part in the modeled space (Figure 8).

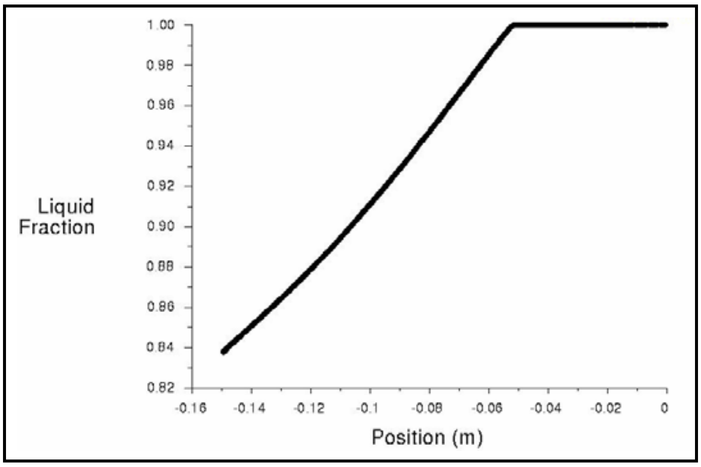

Figure 8 - Graphical output from used model displaying progress of the liquid fraction from the margin to the middle

At simultaneous display of upper and lower part thermal fields of modeled space, the difference of temperature progress is visible. It affects the solidification of the melt in 3D space (Figure 9).

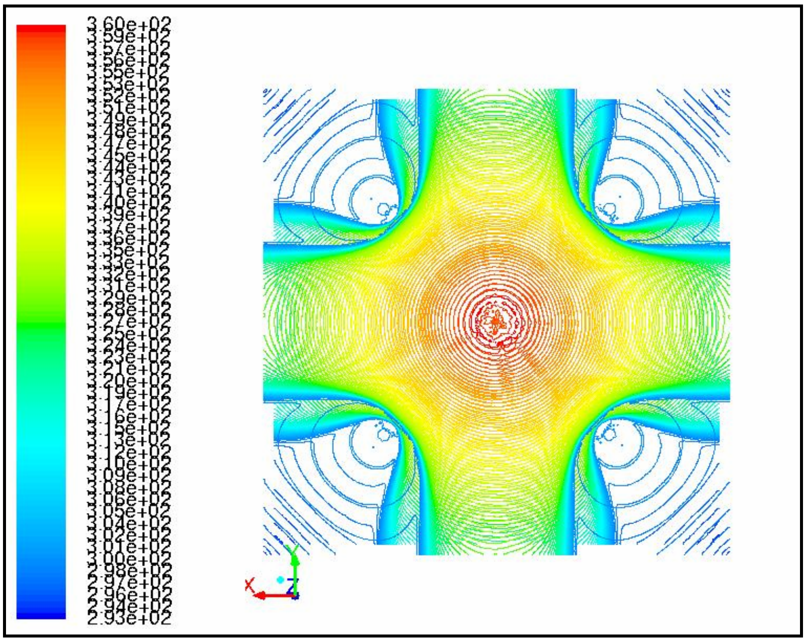

Figure 9 - Temperature distribution in upper and lower part of the model

6. CONCLUSION

One of the specific aims of the project "New detective methods and technologies for extraction of unconventional energetic Earth sources" supported by structural EU funds is excavation of rocks by melting and, within it, checking the formation of radial fractures and penetration range of the resulting melt into the fractures at extremely high temperatures and pressures. To identify the process of melted rock injection into the fractures around drilled borehole it is necessary to know the values of viscosity of the melt at different temperatures or at different melt phases of different rock types. It is also necessary to know the microstructural, mineralogical and petrographical description of rock samples before the experiment start in the pressure chamber.

As solved problems and its results represent entirely new research approach, presented results and output data can not be compared with any other previous data to discuss reached information.

After rock sampling, laboratory methods for sample preparation and sample descriptions of prepared samples from microstructural properties, mineralogical and petrographical point of view were applied.

The result is:

- to prove formation of radial fractures, which form under the conditions of high temperatures and pressures, around drilled borehole;
- to describe the methodology of viscosity measuring of individual melted rocks.

The results are meant for their practical use during the vertical drilling process using Lithojet technology (Lazar et al. 1998; Rybár et al. 2004) for geothermal energy extraction. Due to the fact that these problems were not studied in this form yet, there are many issues to be solved, e.g. to prove penetration of the melt (and its range) into formed fractures. Presented results represent first step of whole research methodology.

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REFERENCES

[1] LAZAR, T. et al. (1998) *A new technology of sinking vertical openings into rock masses (Nova tehnologija bušenja otvora u masivnim stijenama*). In: Metalurgija. Vol. 37, no. 4 (1998), pp. 199-202.

[2] RYBÁR, P. et al. (2004) *Štúdium problematiky tavenia nerastných surovín v extrémnych podmienkach.* Košice: ES/AMS, 2004. 240 p.

[3] SEKULA, F. et al. (1999) *Technológia hĺbenia štíhlych vertikálnych diel tavením*. In: Nové poznatky v oblasti vrtania, ťažby, dopravy a uskladňovania uhľovodíkov. Košice: TU FBERG, 1999. pp. 176-177.