MTDSC analysis of amorphous Nifedipine using sinusoidal and linear modulation of temperature program

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Modulated temperature differential scanning calorimetry (MTDSC) is thermoanalytical technique which involves superimposition of a modulation on the conventional linear heating, cooling or isothermal temperature program. This additional load of the temperature modulation can be described by sinusoidal function (Fig.1a), linear saw-tooth pattern (Fig.1b) or some other mathematical expression. A discrete Fourier transformation of the modulated heat flow (raw signal) yields the dynamic heat flow (Φ_d) and deconvoluted (average) response (Φ_{dc}). The latter is denoted as total heat flow. It can be separated into its heat capacity and kinetic components, also known as reversing (Φ_{rev}) and non-reversing heat flow (Φ_{non}), respectively. Another possibility of interpretation of the results is enabled by calculation of complex heat capacity (C^*_p), which represents the ratio of the modulated heat flow amplitude and modulated heating rate amplitude. C^*_p consists of storage or in-phase heat capacity (C'_p) and loss or out-of-phase heat capacity (C''_p). Reversible responses (like glass transition) are reflected on the C'_p curve. Therefore storage heat capacity can be compared to reversible heat flow signal.

Compared to standard DSC, the modulated technique offers some advantages including enhancement of both sensitivity and resolution in the same experiment, analysis of complex overlapping transitions, direct measurement of the heat capacity and detection of weak glass transitions. Besides the general precautions that are necessary to ensure reliable and accurate results (careful sample preparation, appropriate sample size, use of adequate pans and purge gas, selection of appropriate purge gas flow, calibrations carried out under conditions identical to those used for sample measurement, etc.) it is strongly important to choose an optimised set of MTDSC parameters - the underlying linear heating rate (β), the temperature modulation amplitude (T_a) and the temperature modulation period (t_p).

In the reported study we were concentrated on the analysis of the results obtained with Nifedipine (NIF) as a model compound. Glassy NIF was prepared by quench cooling of the melted samples. The amorphous character was confirmed by X-ray diffractiometry. The MTDSC behaviour of crystalline and amorphous NIF was observed using sinusoidal modulation (Alternating DSC = ADSC, heat flux 821 DSC, Mettler Toledo) and linearly modulated temperature program (Dynamic DSC = DDSC, power compensation Pyris 1 DSC, Perkin-Elmer). In both cases typical MTDSC parameters were: β 1 °C/min, $T_a \pm 1$ °C and t_p 60 s. Such conditions appeared to be the most proper β-T_a-t_p-combination since they provide curves with highest signal-to-noise ratio and sufficient number of modulation throughout the glass transition. DDSC results were treated according to the complex heat capacity approach, whereas ADSC measurements offered the reversing and non-reversing components of the heat flow as well.

Crystalline NIF always indicated single melting peak in the range between 170 and 175 °C. In the case of amorphous NIF glass transition first appeared in the temperature region of 40 - 50 °C. On the heat flow curves this was shown as a decrease of Φ_{rev} (heat flux instrument with "exo-up" orientation) and a small endotherm on Φ_{non}. The following cold crystallization was found to have at least three steps, since Φ_{non} exhibited three exotherms with peak temperatures of 90, 106 and 151 °C. On the reversing heat flow the increase of the signal was noticed at the point, where the first crystallization was finished. The signal remained at the same level till melting at 172 °C.

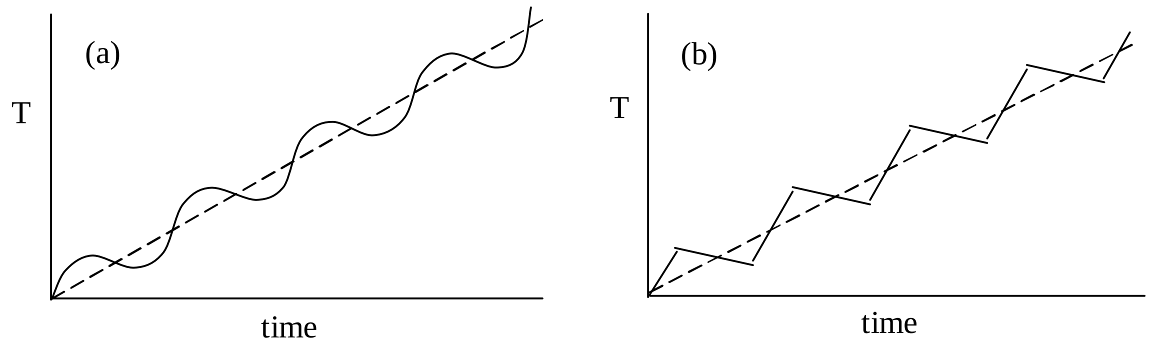

Fig. 1. Temperature as the function of time for a typical DSC (dashed line) and MTDSC experiment with (a) sinusoidal and (b) linear temperature modulation.

From the measurements of amorphous NIF with ADSC, the **heat capacity** curves were also derived. Glass transition was observed with a step increase of complex and storage C_p and an endotherm on the loss C_p. Further on, the crystallization appeared as a decrease of complex and storage C_p and an exotherm on loss C_p at app. 90 °C. After that all of C_p curves remained more or less constant. At 172 °C melting peak was observable on each C_p curve, but studying these signals the event is not fully understood. From the heat capacity results it is clear that first step of cold crystallization at 90 °C causes formation of more structured modification. This is observable from the decrease of the heat capacity. C_p results, however, do not demonstrate the complexity of the crystallization as in the case of heat flow signals.

DDSC results compared to ADSC gave similar responses of the glassy NIF. On the complex and storage C_p curve an increase of the signal at glass transition is followed by its decrease due to cold crystallization. The only difference is the orientation of the peaks on loss signal. C''_p curve gives information on structural and entropy changes. It is therefore directly bound to the enthalpy of the transition and hence influenced by the type of the instrument (“endo-” or “exo-up”). Heating the material, the movements of co-operative units become considerable in the glass transition. This increases the heat capacity and contributes to the entropy of the system, as seen from the endotherm on the C''_p. Crystallization causes the increase of order and the corresponding exotherm on the C''_p indicates the reduction of entropy.

For both types of temperature program the influence of β, T_a and t_p on glass transition temperature (T_g) of NIF was also investigated. The T_g and heat capacity change (ΔC_p) of NIF were determined from complex heat capacity. Only the period of modulation influenced T_g significantly, since C^*_p and its components are frequency dependent. Therefore, T_g values decreased with an increase of period. It was also concluded, that ADSC method gives significantly lower values of T_g than DDSC.

References

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