International Journal of Thermal Sciences 79 (2014) 103–110

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Infrared drying of water based varnish coated on elastomer substrate

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ARTICLE INFO

Article history:
Received 4 August 2012
Received in revised form
17 September 2013
Accepted 14 January 2014
Available online 14 February 2014

Keywords:
Experiment
Nanoindentation
Calorimetric analysis
Numerical model
Inverse method
Crosslinking

ABSTRACT

This study deals with the drying and curing of polyurethane water based varnish by infrared radiation. The varnish is thinly coated on rectangular elastomer substrates. After characterizing their main thermophysical properties, the curing rate is linked to the thermal behavior of varnish. A laboratory setup is developed to retrieve mass and temperature evolutions. First, drying experiments with a constant infrared radiation inferior to 20 kW m^{-2} are performed. The thermal and hydric behaviors of the product are analyzed in term of drying time and heating rate. Then, several experiments with modulated infrared radiation are carried out. The impact of drying conditions on curing rate of varnish is then discussed.

1. Introduction

In industry, rubber profiles designed for the automotive sector are produced on extrusion lines. During its manufacturing, the extruded product successively undergoes many thermal operations. One of them consists in drying and reticulating a thin film of varnish applied on the profile surface. The reticulated varnish protects the profile of its environment (light, humidity), increases its water tightness, accentuates the product brilliance or increases the abrasion protection.

The topical environmental challenges encourage industries to use water based varnishes instead of organic based varnish [1,2]. Thus, the drying step needs a larger amount of energy. A classical solution is to add in the industrial process a superficial radiative heat source, such as infrared technologies [3,4]. Previous works [5,6] have shown the difficulty to dry aqueous polymer solution or dispersion without forming an impermeable skin at the surface of the solution. The use of superficial heating, in case of thin polymer film drying such as varnishes, needs a good control of energy inputs to avoid material deterioration.

This work deals with the infrared heating of a water based varnish containing polyurethane, coated on an elastomer substrate. Due to several physical phenomena involved in the drying (evaporation, shrinkage, crystallization, crosslinking…) [7,8], the product is very sensitive to energy inputs. Thus, to understand well the product's behavior, an experimental laboratory setup, enabling to obtain the drying kinetics of thin coat during drying under infrared radiation, is involved. First, the influence of level of infrared radiation on the heat and mass transfers during the drying is studied. In parallel, a comparison of drying with short-wave and medium-wave infrared radiations is performed. After examining the results, an experimental investigation which consists in modulating the infrared irradiation to dry the product at a constant level of temperature is presented. The final state of crosslinking is linked with the mechanical properties of the varnish by a nanoindentation method, which confirms the possibility to improve the quality of the final product by the control of the infrared inputs.

2. Material and techniques

2.1. Experimental dryer and procedure

The experimental dryer enables to perform experiments with infrared heating combined with natural convection (Fig. 1). The infrared emitters are placed at the upper side of the chamber. Experiments were performed separately with short-wave and medium-wave infrared emitters having a low thermal inertia. The nominal powers of the lamps are respectively of 2 kW for short-wave infrared lamp and 1.5 kW for medium-wave infrared lamp. Each lamp is fitted out with a parabolic reflector to obtain a homogenous radiation on the product surface. A power controller unit

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http://dx.doi.org/10.1016/j.ijthermalsci.2014.01.013

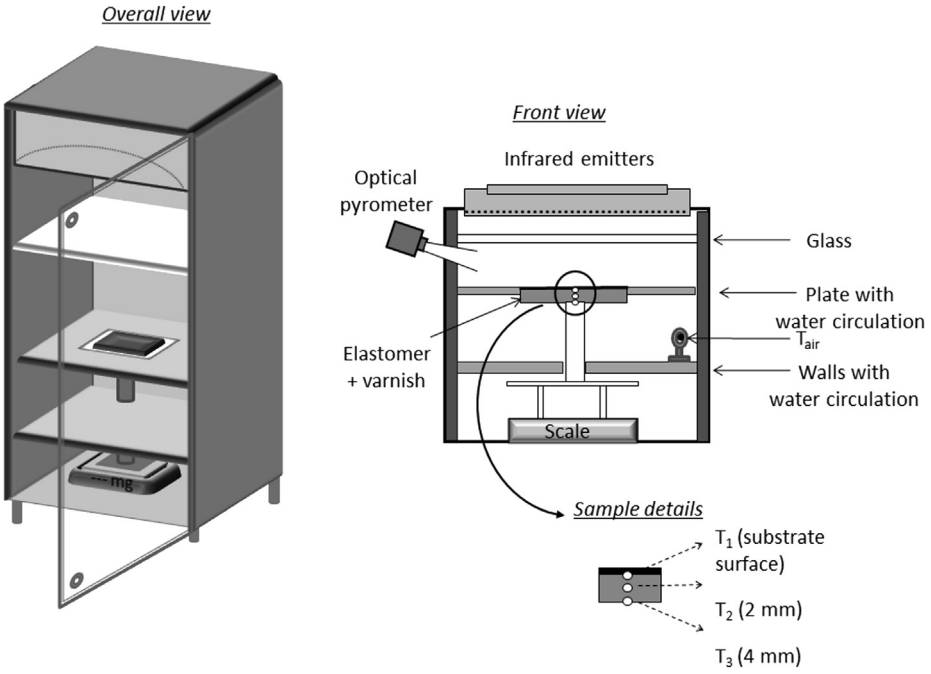

Fig. 1. Experimental setup.

operating in syncopated wave train controls the electrical power supplied to the emitter [9]. This unit is controlled by an input voltage (0–10 V). The infrared radiation received by the product is measured using a sensor developed at the laboratory for both kinds of emitters [10].

The laboratory dryer was designed in order to measure the evolutions of mass and temperatures. Thus, the substrate is placed on a weighting system, located in the chamber. Several precautions are necessary to limit disturbances of mass measurements during the drying stage. Two glass plates are located between the emitters and the sample to avoid convection phenomena involved by emitters' fan inside the chamber. It is also important to avoid the increase of air temperature around the sample during drying. Thus, the chamber is a closed enclosure, whose walls are cooled down with a water circulation. The sample is surrounded with a plate cooled down with the same water circulation.

The sample, schematized in Fig. 1, is constituted of an elastomer plate of dimensions 100 × 50 × 4 mm. A spray gun is used to apply a thin film of varnish, corresponding to a thickness of 80 μm, at the upper surface of the substrate. In order to record the temperature evolutions of the substrate, three K-type thermocouples of diameter 200 μm are placed inside the elastomer: at the surface (T_1), 2 mm-deep (T_2) and 4 mm-deep (T_3). An optical pyrometer measures the surface temperature (T_{surf}) of the varnish. The emissivity is assumed to be constant and equal to 0.93. The measurement of air temperature is also performed by a K-type thermocouple inserted in a cylindrical radiative shield. All sensors are connected to an acquisition system.

Despite the significant precautions taken to avoid it, a drift of the weighting caused by the increase of the air temperature inside the chamber is observed. Thus, before each experiment, a no-load test (substrate without varnish and without thermocouples) is performed to correct it. Then, at each level of infrared radiation, an experiment is performed with a first instrumented coated substrate to measure the temperature evolutions. A second experiment is performed using a coated substrate without thermocouples to avoid disturbances on the mass measurement. Using this configuration, the precision on mass measurement is estimated to 30 mg.

2.2. Material description

A water-based black varnish containing polyurethane is studied. A thermogravimetric analysis (TGA), performed at 2 °C/min, showed that water is not the only volatile constituent of the varnish [11]. Several weight losses were observed before 100 °C, corresponding to an evaporation of solvent. The density of its dried and reticulated base, measured with a pycnometer, is $\rho_{vd} = 1120$ kg m^{-3}. The varnish density is expressed by Ref. [12]:

$$\rho_v = \rho_{vd}\frac{1+W}{1+\psi W} \quad (1)$$

with W the moisture content in dry basis.

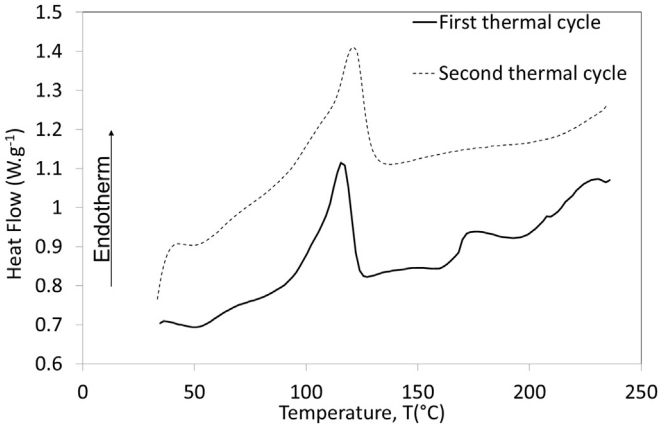

Fig. 2. Calorimetric analysis of dried varnish from 20 °C to 240 °C at heating rate of 20 K/min.