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Influence of different fillers on phenolic resin abrasive composites. Comparison of inverse gas chromatographic and dynamic mechanical–thermal analysis characteristics

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ABSTRACT

The resin resol with selected zeolites fillers and abrasive grain (fused alumina) in a form of cuboid were studied as model material of investigated composites. Inverse gas chromatography (IGC) was used to determine the degree of hardening of studied resol and resol in the filler–resol composites. Dynamic mechanical thermal analysis (DMTA) was used for assessment of the influence of different inorganic fillers on the thermo-mechanical properties of phenolic resin, applied as a binder in manufacturing of abrasive articles. The application of IGC method supported by DMTA analyses makes possible to assess filler/resin interactions and hardening of resin matrix. These results can be applied in industry of abrasive articles. Moreover, presented measurements are cost-effective – there is no need to produce trial product. It was evidenced that fillers reveal significant impact on the thermo-mechanical behaviour of model semi-product used for production of abrasive articles.

1. Introduction

Phenolic resins are commonly used in manufacturing of abrasive articles [1,2]. Two types of them: novolac and resol, both phenol–formaldehyde resins, are most often applied. Novolac is used as a binder. It hardens in the presence of urotropine. Resol (thermosetting polymer) is used as wetting agent (Fig. 1) but it also acts as a binder and hardener of the final product.

Resol is a liquid resin obtained in the reaction of phenol with formaldehyde in the basic environment using excess of formaldehyde (Fig. 2). The nucleophilic phenolic ion (Fig. 2a) undergoes the electrophilic substitution by formaldehyde (Fig. 2b). Due to high reactivity of phenol the mixture of hydroxymethylphenol, bis(hydroxymethyl) phenol and tris(hydroxymethyl)phenol is formed. These hydroxymethyl derivatives of phenol react at higher temperature to resol. The methylene bridges joining the aromatic chains are obtained in the condensation reaction (Fig. 2c). The methylene bridges can arise also in the Michael addition (Fig.2d). Consequently, the resol is a complex mixture (Fig. 1) cross-linked at elevated temperature.

The relatively low price is the advantage of phenol–formaldehyde resins. These are cheaper than ceramic or metallic ones. Abrasive articles with resin binder are produced by hardening at 200°C while in case of ceramic binder at 1200°C. They are soft and highly durable (the cutting speed reaches 45 [m/s]). Binders obtained from phenolic resins are characterised by high durability, flexibility and good polishing properties. Grinding wheels manufactured with the use of phenolic resins as a binder are applied to cutting materials and rough grinding with high cutting speed (45 m/s). Disadvantages of these binders are: sensitivity to coolant containing bases and to high temperature.

The fillers play very important role during the work of the grinding tools, as they collect the heat and prevent the melting of resin [4,5].

Dynamic mechanical–thermal analysis was used to determine the influence of the fillers on the viscoelastic behaviour of the composites expressed by dynamic and damping modulus. Thermo-mechanical properties of resins are closely connected to the cross-linking density achieved after curing process, type of hardener and used fillers [6,7]. The cross-linking is reflected in an increase in the glass transition temperature (Tg) of the polymer and in a rise of storage modulus (G') of the polymer at a given temperature [8].

In this paper inverse gas chromatography was used to determine the degree of hardening of studied resol and resol in the filler–resol composites. This innovative procedure was proposed earlier by co-authors of this paper [4].The influence of fillers on the thermo-mechanical behaviour was also discussed in relation to the IGC derived characteristics (activity of the fillers, their interactions with resol).

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2. Experimental

2.1. Materials

The model semi-products were prepared by mixing resol, filler and abrasive grains by weight: 5:0.3:70, respectively. The amounts of the components were chosen as standard one used in the abrasive industry. The components were mixed by using mechanical mixer with slow rate: 200 rpm for short time (about 3 min). Content of water in resol was equal to ca. 10 wt%. Black fused alumina with a granulation 120 mesh was used as abrasive. Following fillers were used:

- commonly used in abrasive tools industry: PAF (K_3AlF_6 and $KAlF_4$), $Mg(OH)_2$ – powders with granulation about 50 μm (sieve analysis),
- new generation, ecological aluminosilicates: zeolite micro20, synthetic zeolite marked as Z1 – sodium form (powders with granulation about 50 μm determined by sieve analysis). The synthesis of Z1 zeolite was described in detailed in [9]. The ratio Si:Al based on XPS studies was 24:1 and 6:1 for zeolites Z1 and micro20, respectively.

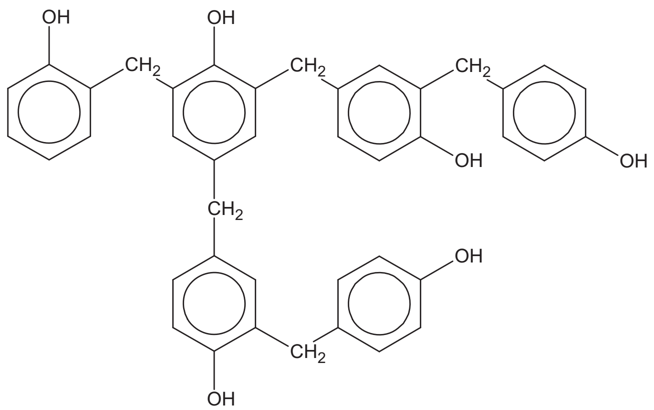

Fig. 1. Approximate structure of resol.

For simplicity, later in this paper following descriptions of tested composites were used:

1. resolS means resolS+abrasive grains,
2. resolS+ $Mg(OH)_2$ means resolS+ $Mg(OH)_2$+abrasive grains,
3. resolS+PAF means resolS+PAF+abrasive grains,
4. resolS+micro20 means resolS+micro20+abrasive grains,
5. resolS+Z1 means resolS+Z1+abrasive grains.

2.2. Dynamic mechanical thermal analysis

The dynamic–mechanical properties of the cured samples with dimensions of $10 \times 4 \times 50\ mm^3$ were investigated by DMTA

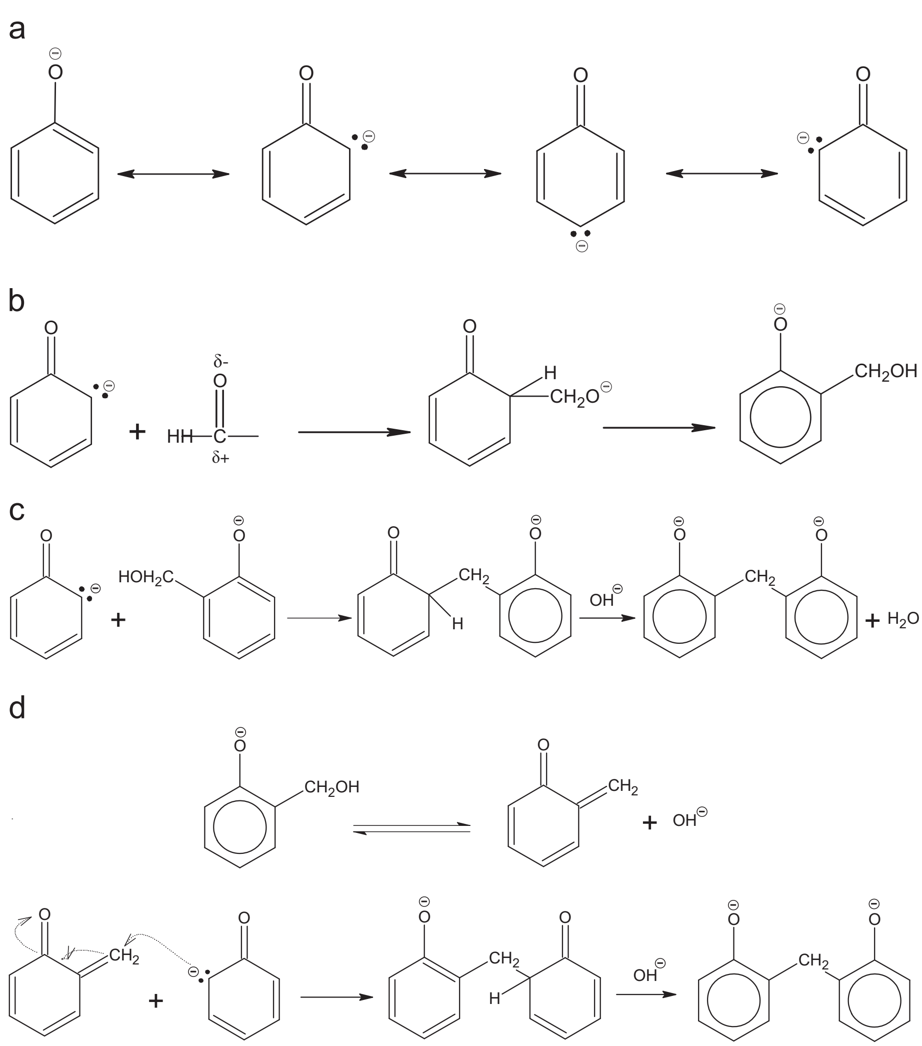

Fig. 2. The reaction of phenol with formaldehyde in the basic environment; (2a) formation of nucleophile from phenol in the presence of base; (2b) reaction of formaldehyde with phenolic anion; (2c) condensation reaction of resol – formation of methylene bridges; (2d) formation of methylene bridges in the Michael addition.