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Wear behavior of polyurethane/carbon black coatings on 6061 aluminum alloy substrates

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ABSTRACT

In this paper, the effects of structural and process variables on wear resistance of polyurethane/carbon black coatings on the 6061 aluminum substrate are studied. These coatings are widely used in different industries because of their outstanding thermal, chemical stabilities and excellent mechanical properties. The parameters were polyol type (ester or ether), NCO/OH ratio and pigment concentration. The experiments were carried out based on the design of experiments using Taguchi method. Abrasion resistance tests were performed with a Taber Abrasion test device, and its morphology was examined by scanning electron microscopy (SEM). Fourier-transform infrared (FTIR) spectroscopy was used to characterize the synthesized polymer. The analysis of variance showed that among the studied parameters, polyol type and pigment concentration have the most significant effects on wear resistance. Coating with polyester polyol increases the wear resistance due to possible hydrogen bonding between hard and soft segments. Furthermore, the pigment particles provide equivalent physical crosslinks, so it increases the wear resistance. Finally, the coated sample including polyester polyol, 12phr carbon black and NCO/OH ratio equal to 1.4, provide the best wear resistance i.e. 0.2 mg. Also, the results showed that abrasion and cohesive wear are the dominant mechanisms for describing the wear behavior of studied coatings.

1. Introduction

Polyurethane plastics can be used in various fields of engineering. After poly olefins, PVC, polystyrene and diene plastics, this polymer is ranked fifth among the useful polymers [1]. This polymer is widely used due to its properties that can be extensively modified by selecting raw materials, catalysts, auxiliary compounds, production method, and final forming process [2–4]. Coatings made from polyurethanes used in many applications, such as aerospace and floor coatings, are being exposed to abrasive materials and need to have enough wear resistance to satisfy the practical and economical aspects [5,6]. Many researchers studied the addition of different nano and/or micro-particles to polyurethane matrix in order to achieve higher wear resistance for production and optimization of thermal control coatings [7]. For example, Zhou et al. added silica nanoparticles to the acrylic based polyurethane matrix and concluded that with increasing silica nanoparticles, the hardness, abrasion resistance, scratch resistance, tensile strength, Young's modulus and absorption in the ultraviolet region increases, but strain at break decreases. For comparison, they also used silica micro-particles and concluded that with adding these particles, only hardness and wear resistance increases [8]. Papaj et al. investigated the effect of the hardener/resin ratio on mechanical properties of commercial polyurethane coatings and concluded that with increasing the hardener/resin ratio, the abrasion resistance of thin coatings increases [9]. Chen et al. prepared the composite of polyurethane/titanium dioxide by sol-gel process, and concluded that with increasing the titanium dioxide content, wear resistance of composite increases [10]. Chen and Wang increased the wear resistance of polyurethane by distribution of α-Al_2O_3 nanoparticles in the polyurethane matrix [3]. Mishra et al. found similar results by adding ZnO nano powder to polyurethane [11]. Taheran et al. studied the effect of polyol molecular weight, diisocyanate type, surface pretreatment method, NCO/OH ratio and pigment volume concentration on wear resistance of white thermal control coatings based on polyurethane/TiO_2 [2].

Despite many works has been done in the field of carbon black pigment [12,13] and polyurethane coatings [8–11]; however, the effects of structural and process variables on wear resistance of polyurethane/carbon black coatings have not been studied well. The purpose of this study is to develop a coating based on

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Table 1
Selected factors and their levels.

Design parameter	Symbol	Unit	Level 1	Level 2	Level 3
Polyol type	A	–	Ether	Ester	–
NCO/OH ratio	B	–	1.4	1.6	1.8
Pigment concentration	C	phr[a]	8	10	12

[a] Parts per hundred parts on polymer.

polyurethane and carbon black pigment for 6061 aluminum substrate with maximum wear resistance. In this study, the effects of polyol type, NCO/OH ratio and carbon black content on wear resistance of thermal control coatings were studied and an optimized formulation was suggested for these kinds of coatings.

2. Experimental

2.1. Materials

4,4′-Methylenebis(phenyl isocyanate) (MDI), *n*-butyl acetate (nBA) and Xylene were obtained from Merck (Germany). Poly(propylene glycol) (PPG, as polyether polyol with molecular weight = 425 g/mol) was supplied by Sigma Aldrich (USA) and Polycaprolactone (Capa2054, as polyester polyol with molecular weight = 550 g/mol) was supplied by Perstorp (UK). Dibutyltin dilaurate (SND3260) was obtained from Gelest (USA). Carbon black (C.I. 77266, Printex V: particle size 25 nm and specific surface area: 100 m^2/g) was supplied by Degussa (Germany) and used as pigment. Furthermore, Disperbyk-161 from BYK Company (Germany) was used for wetting and dispersing of pigments.

2.2. Design of experiments

In Table 1, the effective factors and selected levels were presented. Design of experiments was done using Qualitek-4 software, (Nutek, USA). The orthogonal arrays (L_9), obtained by using this software is summarized in Table 2. The analysis of wear resistance was performed using Qualitek-4 software based on the analysis of variance [14].

Table 2
Experimental design by using Taguchi method (L_9).

Trial	Variables (factors)		
	A	B	C
1	1	1	1
2	2	2	1
3	1	3	1
4	1	1	2
5	1	2	2
6	2	3	2
7	2	1	3
8	1	2	3
9	1	3	3

2.3. Preparation of coating

To obtain the polyurethane resin, 20 g of Poly propylene glycol (PPG) or Polycaprolactone (according to table of experimental design) was reacted with the required amount of diisocyanate (based on specified NCO/OH ratio) in a three-neck flask equipped with a thermometer, reflux condenser, magnetic stirrer, a nitrogen inlet and water bath at 75 °C for 2 h. According to the FTIR spectra of the synthesized prepolymer in run No. 9 (Fig. 1), the disappeared peak of OH groups at 3400–3500 cm^{-1} confirmed the complete reaction of polyol with diisocyanate and consequently the formation of NCO-terminated polyurethane resin. In the next step, disappearance of NCO peak at 2270 cm^{-1} confirms the completion of polyurethane formation. Carbon black pigment was added to the resin according to the design of experiments. Xylene and *n*-butyl acetate were mixed together by equal volume and then added to the mixture to reduce the viscosity. For improving dispersion of pigment in the resin, a small amount of Disperbyk-161 was used and the mixture. Pigments were dispersed in resin with

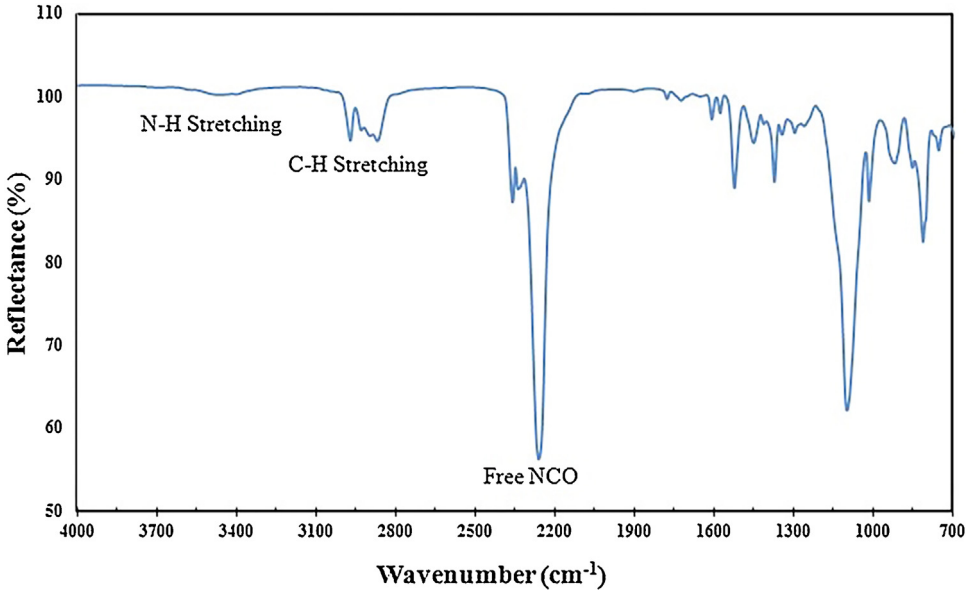

Fig. 1. FTIR spectra of illustrated synthesized PU resin (No. 9).