

Urea-based moulding compounds for investment casting

By

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ABSTRACT

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Conventional urea-based moulding compounds for investment casting patterns are manufactured using a slow “cooking” process. Nowadays in industrial processes the use of a faster process is highly recommended to increase throughput levels. At the same time, for quality control purposes, the requirements of an investment caster must be met. This study is therefore focused on:

- Finding the appropriate conventional process and conditions to prepare urea-based investment casting moulding compounds.
- Optimising the composition variables to meet the mechanical, thermal, surface, flow and cost properties needed in investment casting.
- Characterising the moulding compounds to meet the requirements of an investment caster by comparing them with an industrial, “cooked” urea-based compound.

Polyvinyl alcohol (PVOH) and ethylene vinyl acetate (EVA) urea-based moulding compounds were prepared using a two-roll mill and a conventional extrusion processes respectively. It was possible to injection mould PVOH urea-based moulding compounds with a urea content of up to 90 wt % which had been compounded using a two-roll mill. Using the conventional extrusion

process, it was also possible to compound and injection mould EVA urea-based moulding compounds containing up to 70 wt % urea.

The effects on composition variables on the properties of the moulding compound were studied and compared to those of the existing “cooked” urea-based moulding compound (Benchmark). The mechanical properties were characterised using the three-point bending test and Charpy impact test. The thermal properties were determined using simultaneous differential thermal analysis and thermogravimetric analysis (SDTA/TGA) and differential scanning calorimeter (DSC). The thermo-mechanical and visco-elastic properties were determined using a dynamic mechanical analyser. A scanning electron microscope was used to study the surface texture of the mouldings.

The EVA urea-based moulding compounds showed two endothermic melting peaks and multiple exothermic crystallisation peaks in the DSC curves. The peak at ca. 55 - 66°C corresponds to the melting of the wax/EVA blend, while the large peak at 130 - 132°C corresponds to the melting of the urea. The DSC heating curve of the PVOH urea-based moulding compounds showed two endothermic peaks. The small peak corresponds to the melting of the wax, while the large peak corresponds to the melting of the urea/PVOH blend.

PVOH urea-based moulding compound had better mechanical properties than the industrial benchmark. The mechanical properties of the EVA urea-based compound were generally lower. The effect of the wax and polymer content on the mechanical properties was as follows:

- Increasing polymer content produced weaker but tougher moulding compounds.
- Increasing wax content improved the strength and stiffness but gave compounds that were less tough.
- Two-way Analysis of Variance (ANOVA) indicated significant polymer-wax interactions.

The urea content determined the stiffness (elastic modulus) of the compounds. PVOH mouldings had superior stiffness compared with the EVA and cooked urea-based mouldings. The Dynamic mechanical analysis (DMA) results confirmed the result obtained from the modulus of elasticity determination in the three-point bending test.

The impact strength increased with an increase in polymer content and reduced with an increase in wax content.

The linear thermal expansion coefficient decreased as the urea content was increased. Measured values (100 to 156x10⁻⁶ °C) were comparable to those of the benchmark.

The cooked urea-based moulding compound had the lowest melt viscosity at 110°C, as indicated by its melt flow index (MFI). Fluidity increased with the polymer content.

The thermo gravimetric analysis (TGA) results confirmed that both the PVOH and EVA urea-based moulding compounds decomposed readily and left less than 1 wt % ash after combustion.

From the SEM results apparent surface roughness appeared to increase with wax content. The EVA urea-based moulding compound had an irregular surface texture.

Based on the criteria of cost-effectiveness and environmental friendliness, the synthesis of PVOH urea-based patterns is preferable. The use of a conventional extrusion process to prepare PVOH urea-based patterns is recommended.

Keywords:

Urea, wax, ethylene vinyl acetate, polyvinyl alcohol, non-biodegradable pattern, biodegradable pattern, investment casting

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LIST OF ABBREVIATIONS

ANOVA	=	Analysis of variance
DMA	=	dynamic mechanical analysis
DMF	=	dimethyl formamide
DSC	=	differential scanning calorimeter
EVA	=	ethylene vinyl acetate
MFI	=	melt flow index
PEG	=	polyethylene glycol
PET	=	polyethylene terephthalate
PVC	=	polyvinyl chloride
PVOH	=	polyvinyl alcohol
phr	=	parts per hundred of resin
SEM	=	scanning electron microscope
SDTA	=	Scanning differential thermal analysis
TGA	=	thermogravimetric analysis
TMA	=	thermomechanical analysis
UE	=	EVA urea-based moulding compound
UF	=	resin
UP8	=	PVOH urea-based moulding compound of plasticisation degree 80
UP4	=	PVOH urea-based moulding compound of plasticisation degree 40
VA	=	vinyl acetate
X: Y: Z	=	proportion of urea: polymer: wax

LIST OF SYMBOLS

A	=	weight of the sample in air (g)
B	=	weight of the sample immersed in water (g)
B	=	width of beam tested (mm)
c	=	volumetric fraction of polymer
D	=	maximum deflection of the centre of the beam
D	=	depth of beam tested (mm)
E	=	modulus
E_B	=	Young's modulus of bending
ε	=	strain at time t
ε_0	=	strain at a maximum strain
F_Z	=	force in the Z direction
H	=	height
L	=	liquid phase
L_S	=	support span
L_1	=	length at T_1
L_2	=	length at T_2
M	=	measured torque
M_D	=	maximum deflection
M_L	=	maximum load
n	=	number of components in the blend
ρ_s	=	density of the sample (g/cm^3)
ρ_L	=	density of liquid (g/cm^3)
ρ_C	=	density of the moulding compound
ρ_i	=	density of the component
w_j	=	weight fraction of component
r	=	radii of the particles
R	=	cone radius
S	=	solid phase
T	=	time
ΔT	=	change in temperature

m	=	steepest load deflection curve slope
T_{om}	=	onset melting temperature
T_c	=	crystallisation temperature
T_{oc}	=	onset crystallisation temperature
T_g	=	glass transition temperature
T_{g1}	=	glass transition temperature of the polymer
T_{g2}	=	glass transition temperature of the plasticizer
U	=	velocity
V	=	vapour phase
V_1	=	free volume
V_o	=	occupied volume
W_D	=	work done
w_1	=	weight fraction of the polymer
w_2	=	weight fraction of the plasticizer
ω	=	frequency of oscillation
w_i	=	weight fraction of component
γ	=	surface tension
α	=	coefficient of linear thermal expansion
Ω	=	rotational velocity
Φ	=	angular displacement; $\beta = \theta - x/2$ (typically 2°-8°)
θ	=	cone angle
σ	=	stress at time t
σ_0	=	maximum stress
η	=	viscosity
η_e	=	elongation flow
η_s	=	shear flow
$\dot{\gamma}$	=	shear rate