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Rheological properties of feedstocks for powder extrusion molding ①

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[Abstract] The rheological behaviors of feedstocks for powder extrusion molding, in the temperature range of 40 ~ 80 ℃ and the Newton shear rate $\dot{\gamma}$ of 3 ~ 800 s^{-1}, were studied. The effects of feedstock constitution, shear rate and temperature on apparent viscosity, shear stress and active energy were investigated. The viscose-flow active energy of PEM feedstocks is 15.89 ~ 90.77 kJ/mol. Based on this research, the PEM technical parameters have optimized.

[Key words] powder extrusion molding; feedstock; rheological property; apparent viscosity
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1 INTRODUCTION

With its fast development and wide application, powder extrusion molding (PEM) has become one of the most primary methods in powder metallurgy field which can be used to manufacture the tubes, rods and other shapes of cemented carbide, high-density alloy, other metals and alloys[1,2]. The technical hard-core include binder design and fabrication[3~6], rheological measurement, process control[7,8] and debinding[4,5,9~11]. The feedstocks for PEM are made of binder and powders. Adding the binder in the feedstocks makes it easy to mold. So it is very important to study rheological behaviors of the feedstocks with different binder addition.

In this paper, several kinds of binder and feedstock are designed and manufactured. The effective method for controlling the extrusion quality and improving the production efficiency are analyzed.

2 EXPERIMENTAL

The binders b1, b2, and b3[7,9] were manufactured by melting-out combined with solvent dissolving. The powders with composite of WC 92% and Co 8% (mass fraction) (named YG8) were used. The YG8 powders and binder were mixed and plasticized in BRABENDER tester. In the feedstocks (named bp1, bp2 and bp3, corresponding to binders b1, b2 and b3 respectively), the contents of YG8 powders were 95.3%, and the contents of binder were 4.7% (mass fraction). The feedstock homogeneity was estimated by the torque-time curves. After about ten minutes' iso-torque procedure, it is considered that the binder and powders were mixed evenly.

The rheological characteristics of feedstocks were measured by means of MPT (Monsanto Processability Tester) in the temperature range of 40 ~ 80 ℃ and the Newton shearing rates $\dot{\gamma}$ of 3 ~ 800 s^{-1}. The MPT is one type capillary with diameter of 0.145 cm, length of 2.90 cm, H/D ratio of 20.

3 RESULTS AND DISCUSSION

The experimental results are listed in Table 1.

The rheological behaviors of PEM feedstocks can be expressed by shear stress:

$$\tau = k\dot{\gamma}^n \quad (1)$$

where $\dot{\gamma}$ is Newton shear rate, k and n are material functions. Here, apparent viscosity, η_a, is defined as

$$\eta_a = k \cdot \dot{\gamma}^{n-1} \quad (2)$$

Then

$$\tau = \eta_a \cdot \dot{\gamma} \quad (3)$$

Fig.1 shows shear stress—shear rate ($\tau - \dot{\gamma}$) curves of the three kinds of feedstocks. The feedstocks can be considered as pseudo-plasticity fluids, with non-Newton index $n < 1$. In the range of experimental temperatures and shear rates, the shear stress increases with increasing of shear rate, but decreases with increasing of temperature. The technical parameters can be optimized by suitable controlling the shear rate ($\dot{\gamma}$) and temperature (T), and at the same time considering the influence of $\dot{\gamma}$ and T on η_a. Then the extrusion molding green-bodies with good quality can be successfully manufactured.

Fig.2 shows the relations between η_a and non-Newton shear rate, $\dot{\gamma}'$. The $\eta_a - \dot{\gamma}'$ curves can more sensitively show the non-Newton characteristics than $\tau - \dot{\gamma}$ curves. Apparently, in the experimental temperature ranges, increment of shearing rate can decrease the viscosity of feedstocks and improve their rheological properties; while $\dot{\gamma}'$ increases to a certain value, increment of $\dot{\gamma}'$ can not obviously decrease the

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value of η_a. So by selecting suitable value of $\dot{\gamma}$, η_a does not decrease notably, so as to continuously produce extrusion green-bodies with good quality.

By analyzing the relationship between η_a and T, the viscose-flow activation energy, E, can be calculated by Arrhenius equation:

$$\eta_a = A e^{E/(RT)} \quad (4)$$

where A is a constant, R is general gas constant, T is absolute temperature.

From Eqn.(4),

$$\lg \eta_a = \lg A + E/(2.303\,RT) \quad (5)$$

The active energy of the three types of feedstocks are listed in Table 2. In Table 2, R_L is the correlative coefficient whose value is close to 1.

Table 1 Shear stress, apparent viscosity and non-Newton index of feedstocks

Feedstock	T/K	Shear rate, $\dot{\gamma}$/s^{-1}	Shear stress, τ/Pa	Apparent viscosity, η_a/(Pa·s)	Non-Newton index, n
bp1	323	3.652	29 308.3	7 291.1	0.7127
		36.52	153 436	3 848.2	0.7313
		365.2	710 288	1 574.8	0.5154
		730.4	982 680	1 025.5	0.4479
	333	3.652	12 930.4	2 547.3	0.3906
		3.652	34 480.4	753.30	0.4966
		3.652	137 920	342.21	0.7069
		730.4	228 430	287.32	0.7384
	343	3.652	9 482.58	1 751.5	0.3412
		36.52	24 136.8	542.84	0.5347
		365.2	107 750	264.81	0.6864
		730.4	172 400	210.57	0.6739
bp2	313	3.652	68 098.6	5 560.9	0.09836
		36.52	86 200.4	784.07	0.1106
		365.2	181 020	454.36	0.7331
		730.4	327 560	438.55	0.9168
	323	3.652	51 720.5	3 804.4	0.06306
		36.52	64 650.8	780.29	0.1646
		365.2	137 920	314.92	0.5564
		730.4	211 190	254.03	0.6438
	333	3.652	25 860.3	3 603.5	0.02057
		36.52	41 376.5	568.00	0.2009
		365.2	86 200.0	197.20	0.5593
		730.4	133 610	162.78	0.6687
	343	3.652	21 550.8	1 680.9	0.09055
		36.52	30 170.8	479.85	0.2573
		365.2	81 890.3	194.41	0.6196
		730.4	129 300	158.29	0.6786
	353	3.652	8 620.49	1 696.9	0.3899
		36.52	21 550.3	435.02	0.4139
		365.2	62 064.0	138.75	0.5265
		730.4	90 510.0	103.10	0.5532
bp3	313	3.652	275 840	40 128	0.2207
		36.52	465 480	7 117.4	0.2402
		365.2	827 520	1 294.5	0.2498
		730.4	982 680	763.46	0.2469
	323	3.652	51 720.4	5 169.6	0.1256
		36.52	69 822.0	752.90	0.1397
		365.2	136 196	315.20	0.5770
		730.4	215 500	267.05	0.7045
	333	3.652	35 342.2	5 041.9	0.2137
		36.52	56 030.8	698.59	0.1728
		365.2	112 060	262.75	0.5983
		730.4	181 020	227.71	0.7387
	343	3.652	30 170.6	2 229.3	0.08457
		36.52	39 652.6	520.17	0.1869
		365.2	86 200.0	193.99	0.5355
		730.4	129 300	152.61	0.6897

Table 2 Active energy and corresponding relative coefficient of feedstocks

Feedstock	$\dot{\gamma}$ = 3.652 s^{-1}		$\dot{\gamma}$ = 36.52 s^{-1}		$\dot{\gamma}$ = 365.2 s^{-1}		$\dot{\gamma}$ = 730.2 s^{-1}	
	E/(kJ·mol^{-1})	R_L	E/(kJ·mol^{-1})	R_L	E/(kJ·mol^{-1})	R_L	E/(kJ·mol^{-1})	R_L
bp1	65.98	0.968 874	90.77	0.939 559	82.67	0.931 294	73.33	0.949 251
bp2	22.31	0.999 526	17.62	0.999 606	15.26	0.996 283	14.88	0.992 112
bp3	24.93	0.986 427	19.93	0.971 012	16.68	0.983 518	15.89	0.990 916

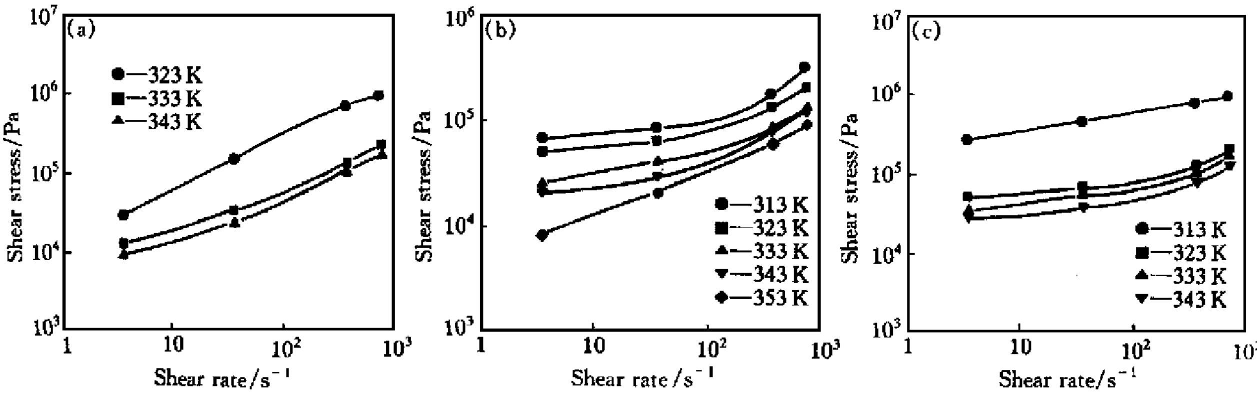

Fig.1 $\tau-\dot{\gamma}$ curves of feedstocks

(a) —bp1 ; (b) —bp2 ; (c) —bp3

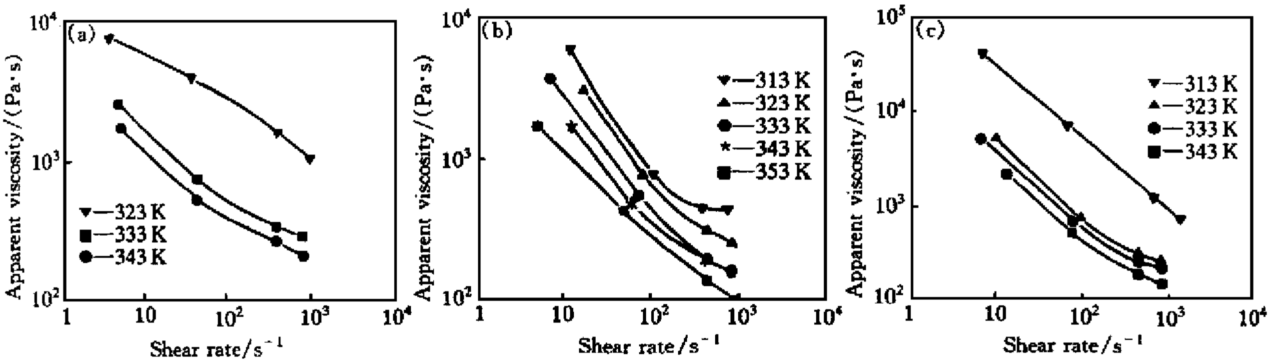

Fig.2 $\eta_a-\dot{\gamma}$ curves of feedstocks

(a) —bp1 ; (b) —bp2 ; (c) —bp3

From Table 2, it is found that the viscose-flow activation energy (E) is not very big. This shows the effect of temperature on viscosity is small. Also it is found that the correlative coefficient R_L of feedstock bp2 is closet to 1, the value of E is most reliable. In extrusion molding experiments, the feedstock bp2 shows good general properties, which indicates that the binder b2 is the optimal composite under the experimental conditions.

4 CONCLUSIONS

With new binder, the PEM feedstocks with good quality are prepared. The experimental results show that the characteristics of sample bp2 is optimal. By optimizing PEM technical parameters, the extrusion green-bodies with good quality can be continuously extruded.

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