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DISTRIBUTIVE MIXING PERFORMANCE OF RUBBER INTERNAL MIXERS

By

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ABSTRACTS

Results of experiments to study the distributive mixing performance of Internal mixers are reported in this paper. Distributive mixing was assessed by monitoring the uniformity of sulphur distribution throughout rubber mixes subjected to a range of rotor revolutions. The results indicate that distributive mixing in a well controlled Internal mixer is rapid and unlikely to be a source of mix variability.

1.0 INTRODUCTION

The Internal mixer is known as the work horse of the rubber Industry. It is used for mixing a wide range of additives and fillers with the polymer. These ingredients are responsible for converting the raw polymer into a useful engineering material, and they may be classified into cure systems, reinforcing fillers, processing aids and miscellaneous ingredients (1). All these must be well dispersed and distributed within the compound mass. A typical internal mixer today is represented by a Bambury Mixer and Francis Shaw Intermix (2) and it consists of a mixing chamber with two rotors equipped with wings rotating in opposite directions, a feed hopper for feeding the material and a floating weight (ram) used to confine the material to the mixing region (3).

The modes of operation of an internal mixer maybe classified as follows (4):

Region I: A region of random flow with low intensities of shearstrain rate and shear stress, to perform the task of incorporation and simple or distributive mixing.

Region II: A region of unidirectional flow with high intensities of shear strain rate and shear stress, to perform the task of dispersion but also helpful in incorporation and distributive mixing.

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Most studies have focused on dispersive mixing performance of the internal mixer,(3, 4, 5). Previous studies by this author (6) on Industrial mixing showed that dispersion achievable routinely is adequate. In this study the performance of industrial mixers as regards distributive mixing will be explored. The approach to be taken is to use the uniformity of sulphur distribution throughout rubber mixes subjected to a range of rotor revolutions (mixing times) as a measure of the distributive mixing performance of an industrial internal mixer. The mixer used is the Farrel Bridge F40.

2.0 EXPERIMENTAL SCHEME

The experiment was divided into two parts:

PART I - To investigate effects of time of mixing sulphur (number of rotor revolutions) on compound uniformity.

PART II - To investigate the effect of mixing sulphur at the same number of rotor revolutions (30 rotor revolutions) at varying time and rotor speed.

The formulation used for these experiments was; (i) EPDM, 100 pphr (parts per hundred of resin), (ii) Carbon Black, 180 pphr (iii) oil, 100 pphr (iv) Sulphur, 2.5 pphr and (v) Accelerator and other minor ingredients, 2.4 pphr.

The ram pressure used on the mixer was 0.6 MPa, the fill factor was 0.75 and the circulating water temperature was maintained at 25 °C. The initial rotor speed used was 40 rpm. Mixing was started by adding all powders (except sulphur) and oil in the mixer. Rubber was added 1 min. later and sulphur was added 2 min. after the addition of Rubber.

PART I:

After adding sulphur mixing continued for the following times.[2]

Batch	Mixing Time (sec.)	No. of Rotor Revolutions
1	15	10
2	30	20
3	45	30
4	60	40
5	75	50
6	90	60
7	120	80

PART II:

After adding sulphur the rotor speed was changed to:

Batch	Rotor Speed (rpm.)	Dump Time (sec.)
1	20	90
2	30	60
3	40	45
4	50	36
5	60	30

Sampling

Each batch was passed once though the mill nip to give a relaxed sheet thickness of about 10 mm. Eight samples were taken randomly from well spaced locations so as to be representative of the sulphur distribution throughout the batch.

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[2] Times refer to time after final ram down.

3.0 Testing

Sulphur distribution in the batches was estimated by measuring cure characteristics using a monsanto Oscillatory disc Rheometer (ODR) (7).

4.0 Results

PART I

The batch mean values and the corresponding coefficient of variations are given in Tables 1 to 4. The mean values and the coefficient of variations are also plotted against number of rotor revolutions (figs. 1 and 2).

PART II

All Part II results are presented in Tables 5 to 8. These tables show the batch means, standard deviations, and the coefficient of variations.

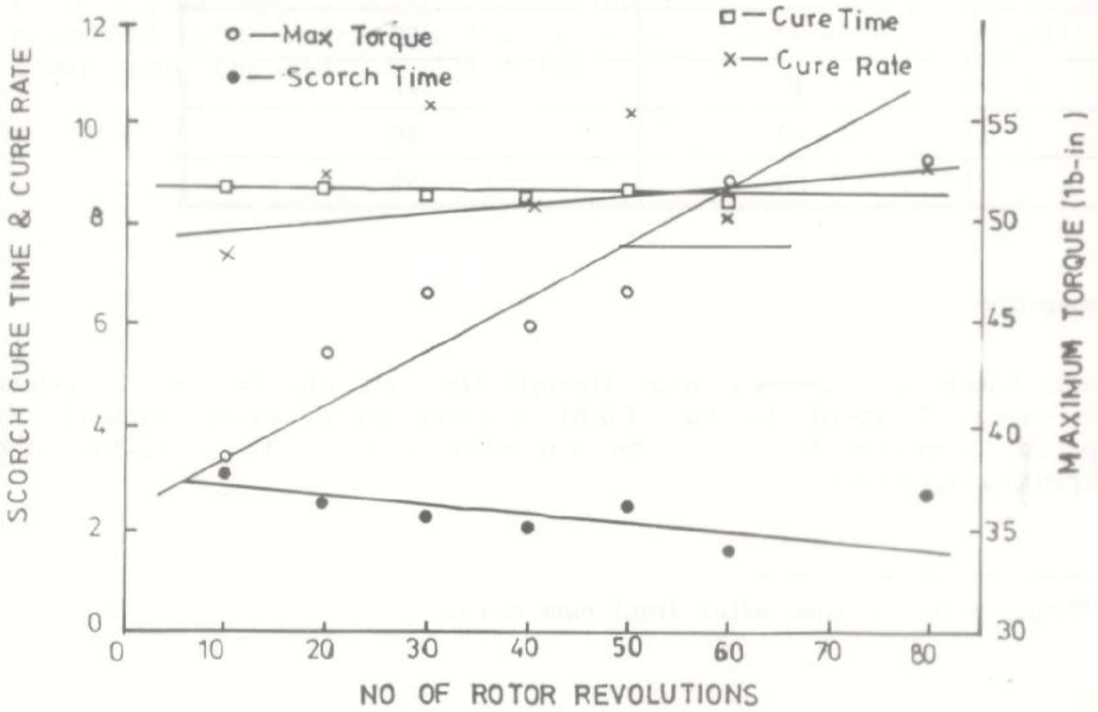

Fig.1: Mean ODR Trace Characteristics-v-Rotor Revolutions.

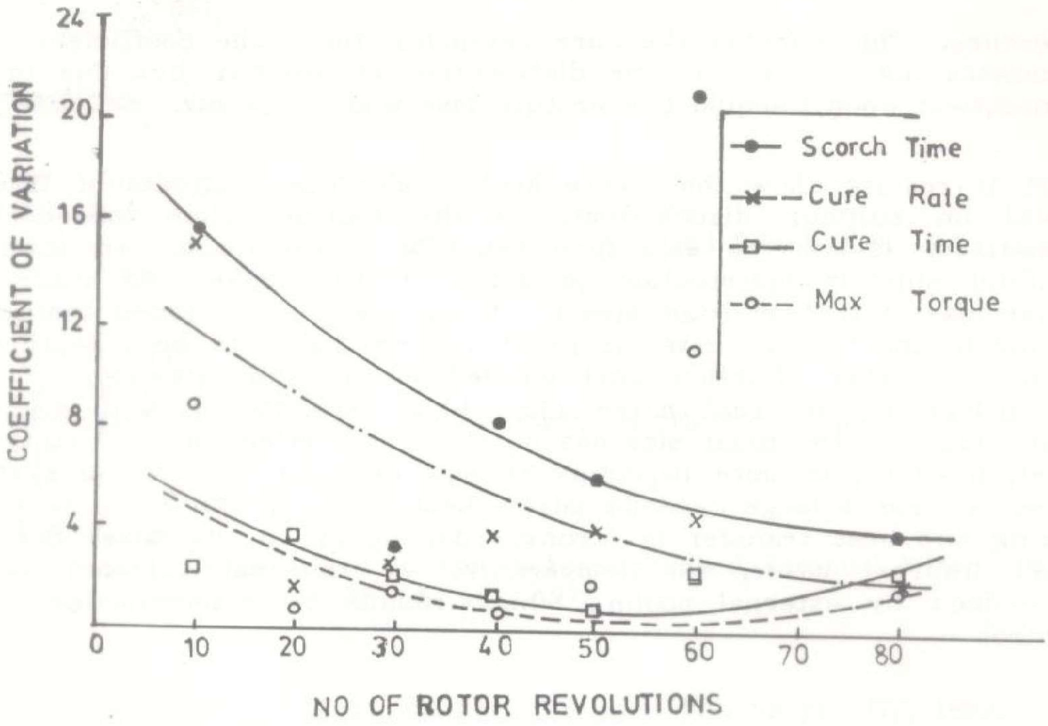

Fig.2: Mix Uniformity - v- Rotor Revolutions.

5.0 DISCUSSION OF RESULTS AND CONCLUSIONS

Since no replicate measurement on sample was done, the measurement error (which is significant on ODR traces) can not be separated from the sampling error. This inevitably introduces a certain amount of error and has to be kept in mind when looking at the results.

Mean scorch and cure times decrease with increasing rotor revolutions, while cure rate and maximum torque increases (fig. 1). The Rheometer cure characteristics are seriously influenced by mix heat history. During part of each rotor revolution of the mixer, a portion of the rubber is sheared between the nogs and blades projecting from the rotors and the walls of the chamber. As the clearances are small the shear rates are high, there is considerable heat build up. As the time of mixing or the number of rotor revolutions increases so also will the heat build up increase. This will affect cure characteristics.

With 10 rotor revolutions, the compound has not experienced sufficient lamina shear mixing, adequate for uniform distribution of sulphur and, therefore, the coefficient of variation of the batch is high. In general the coefficient of variation decreases rapidly until about 40 rotor revolutions when it levels off, indicating that the optimum distribution of sulphur has been reached (fig. 2). With 60 rotor revolutions, heat builds up causing some scorching and pre-cure. This affected the cure characteristics. The coefficient of variation increases not due to uniform distribution of sulphur but due to scorching consequent upon unequal temperature rise within the mix.

Part II results show that there are no significant effects of time or rotor speed on sulphur distribution. All the batches show low coefficient of variations. It may be said then that for a well controlled internal mixer, uniform sulphur distribution is achieved after about 40 rotor revolution regardless of time or rotor speed. It may also be concluded that distributive mixing in the internal mixer is rapid and not likely to be a limiting factor in industrial mixing. Further work carried out by Ekhorutomwen (8), on a small BR Laboratory internal mixer (1.5) litre capacity) showed similar results indicating that the mixer size has no significant effect on uniformity of mixing. What, however, is more important is how efficient the cooling system of the mixer is. For a large capacity mixer, heat build up can be quite high during mixing and heat transfer is strongly dependent on the mixer design. For a small internal mixer, the temperature of the material can be strongly influenced by external cooling which results in easier mixing temperature control.

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Table 1 Scorch Time (min.)

No.of Rotor Revolutions	10	20	30	40	50	60	80
Mean	3.11	2.56	2.28	2.08	2.4	1.66	2.710
S.D.	0.488	0.071	0.071	0.167	0.141	0.35	0.083
C.V.(%)	15.70	2.74	3.10	8.02	5.88	21.1	3.80

Table 2 : Cure Rate (1b - in/min.)

No. of Rotor Revolutions	10	20	30	40	50	60	80
Mean	7.32	8.97	10.28	8.30	10.26	8.27	9.17
S.D.	1.107	0.132	0.244	0.287	0.355	0.368	0.171
C.V.(%)	15.12	1.47	2.37	3.46	3.46	4.44	1.86

Table 3 : Cure Time (min.)

No. of Rotor Revolutions	10	20	30	40	50	60	80
Mean	8.84	8.75	8.68	8.54	8.65	8.34	9.1
S.D.	0.207	0.321	0.198	0.106	0.076	0.177	0.185
C.V. (%)	2.34	3.67	2.28	1.24	0.87	2.12	2.03

Table 4 : Maximum Torque (lb-in).

No. of Rotor Revolutions	10	20	30	40	50	60	80
Mean	38.28	43.63	46.66	44.8	46.51	52.15	44.2
S.D.	3.39	0.33	0.78	0.39	0.80	5.75	0.50
C.V. (%)	8.85	0.745	1.52	0.877	1.73	11.03	1.73

Table 5 : Scorch Time (min.).

Rotor Speed (rpm.)	20	30	40	50	60
Mean	2.51	2.2	2.28	2.04	1.9
S.D.	0.064	0.119	0.071	0.119	0.076
C.V. (%)	2.55	5.43	3.10	5.82	3.98

Table 6: Cure Rate (lb-in/min.).

Rotor Speed (rpm.)	20	30	40	50	60
Mean	9.38	8.43	10.28	10.02	9.29
S.D.	0.300	0.115	0.244	0.300	0.245
C.V. (%)	3.20	1.36	2.37	3.09	2.63

Table 7: Cure Time (min.)

Rotor Speed (rpm.)	20	30	40	50	60
Mean	8.65	8.56	8.68	8.63	8.56
S.D.	0.233	0.115	0.198	0.046	1.87
C.V. (%)	2.69	1.36	2.28	0.54	1.87

Table 8: Maximum Torque (lb-in)

Rotor Speed (rpm.)	20	30	40	50	60
Mean	43.6	42.69	46.67	49.56	48.75
S.D.	0.793	0.603	0.711	0.700	0.775
C.V. (%)	1.82	1.41	1.52	1.41	1.59