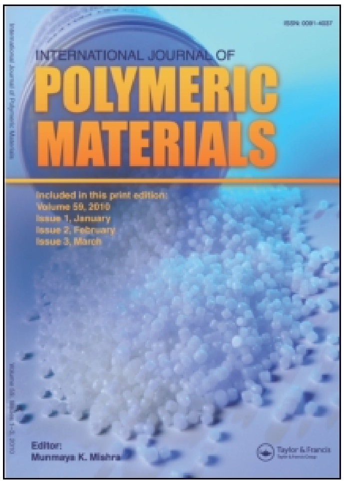

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Analysis of Theories in Computer Programmes for Estimation of Conveyor Belt Curing Time Part II: Errors in Estimation of Curing time

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Effect of errors in the measurement of input data on the estimation of conveyor belt curing time are discussed and analysed by means of a computer programme. State of cure as affected by variations in temperature coefficient of vulcanisation and current views in this connection are also discussed. Other factors considered are thermal diffusivity, top and bottom plate temperatures, and experimental curing time and temperature.

KEY WORDS Conveyor belt, curing times, error estimation of curing time

NOTATION

K = Temperature coefficient of vulcanisation
S_t = Equivalent time at temperature T_r (min)
T = Temperature of the part in time δt (°C)
T_r = Experimental curing temperature of reference material (°C)
δt = Time interval (min)

INTRODUCTION

In part one of the present article the Lepetov and Sahand methods for estimation of conveyor belt curing time were compared and contrasted in the light of the equivalent thickness theory.[1] The Sahand computer method was developed using the heat transfer characteristics of a conveyor belt and programme input data included thermal diffusivity and temperature coefficient of vulcanisation of carcass and top and bottom covers, initial temperature, top and bottom plate temperatures, experimental time and temperature for 90% cure of carcass and top cover, and time interval.

In the present paper susceptibility of the computed conveyor belt curing time to variations and errors in the measurement of above factors is investigated.

EFFECT OF TEMPERATURE COEFFICIENT OF VULCANISATION ON STATE OF CURE

Curing time for a rubber part may be obtained from the equation

$$S_t = \delta t K^{(T - Tr)/10} \quad (1)$$

In the Sahand computer programme temperatures of points within the part are calculated at various time intervals and equivalent curing time for the points determined by means of Equation (1). The curing of a layer is assumed to be complete when the sum of equivalent curing times thus obtained equals the experimentally determined curing time.

Differing views have been expressed in the literature concerning the actual value of temperature coefficient of vulcanisation, K. According to Hills[2] temperature coefficient of vulcanisation is independent of temperature, its value depending on the nature of the compound particularly the type of accelerator. For a mixture of rubber and sulphur the value is 2.59, with MBT accelerator it is 1.9, and in general with formulation used nowadays values between 1.9 and 2.1 are appropriate. Lepetov[3] and Edmondson[4] considered K a constant equal to 2, while Prentice and Whliams[5] used a value of 1.85 in their studies. In an article by Hands and Horsfall[6] of RAPRA it was stated that temperature coefficient of vulcanisation was usually assumed to be a constant, and in experiments using two compounds of natural rubber a value of 1.9 was obtained, although rheometer results indicated that K was temperature dependent and in the range 120 to 200°C its value decreased by almost 50%. Variation of K with temperature as reported in the above article is reproduced in Figure 1. The straight line has equation

$$K = 0.012T + 3.78 \quad (2)$$

In order to examine the results of Hands and Horsfall, Equation (2) was fed into the Sahand computer programme to determine values of K at various temperatures. Input data used are shown in Table I.

Figures 2 to 4 show the variation of K with temperature during curing of top cover, carcass and bottom cover, respectively, at 0.5 mm point intervals. The average value of K calculated for the layers is 1.85, 1.95 and 1.9, giving an overall average of 1.9 for the belt as a whole. It is clearly seen that variation of K with temperature is significant only during the first few minutes of cure probably due to rapid increase in temperature of the part during this time. After this period temperature is in the range 145 to 160°C and K can be assumed constant with little error.

It must be noted that the curing time determined in this manner differs by a mere 0.5 minutes from the case in which the value of K for top cover and carcass is 1.75, and that no difference is observed if a value of 1.9 is assumed for the layers.

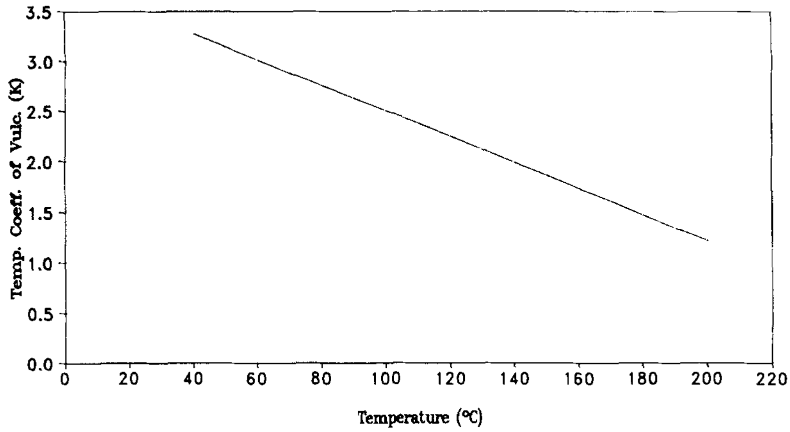

FIGURE 1 Variation of temperature coefficient of vulcanisation with temperature (after Hands and Horsfall[6]).

TABLE I

Programme input data for variation of K with temperature

Top cover thickness (mm)	3.0
Carcass thickness (mm)	3.5
Bottom cover thickness (mm)	1.5
Thermal diffusivity of cover (m^2/hr)	$3.33e^{-4}$
Thermal diffusivity of carcass (m^2/hr)	$3.53e^{-4}$
Top plate temperature (°C)	160
Bottom plate temperature (°C)	150
Initial temperature (°C)	40

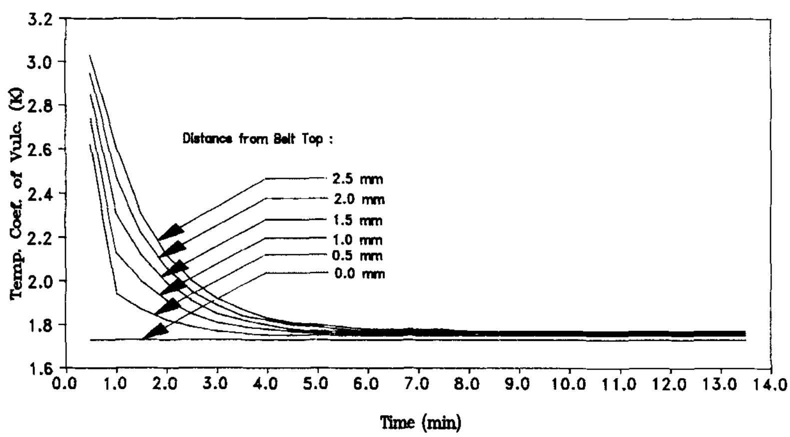

FIGURE 2 Variation of temperature coefficient of vulcanisation during cure of top cover.

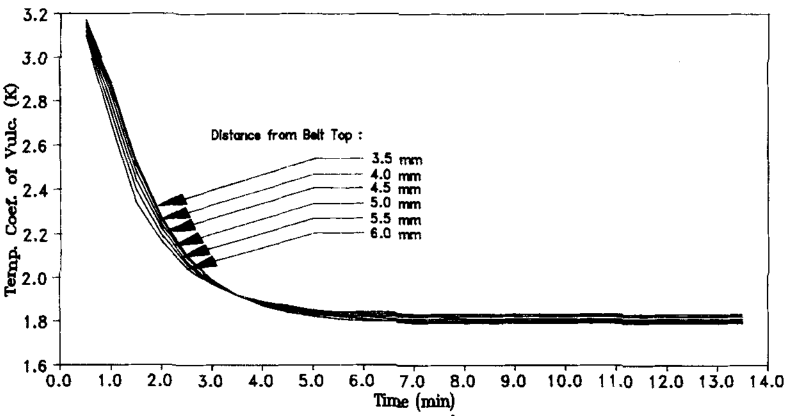

FIGURE 3 Variation of temperature coefficient of vulcanisation during cure of carcass.

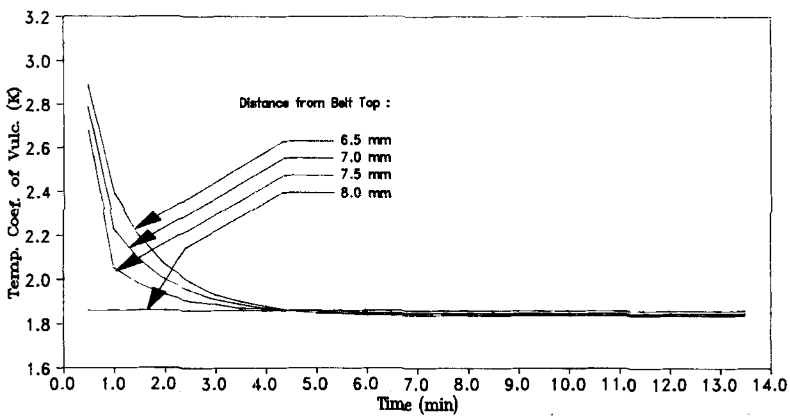

FIGURE 4 Variation of temperature coefficient of vulcanisation during cure of bottom cover.

TABLE II

Programme input data for variation of curing time with thermal diffusivity and part thickness

Top and bottom plate temperatures (°C)	160
Initial temperature (°C)	40
Temperature coefficient of vulcanisation	1.9
Experimental curing time (min)	7
Experimental curing temperature (°C)	160

EFFECT OF THERMAL DIFFUSIVITY AND PART THICKNESS ON CURING TIME

Conflicting observations regarding the variation of thermal diffusivity with temperature have been published. Khouider *et al.*[7] assumed the thermal diffusivity to be independent of temperature while others[5,8,10] believed it to be temperature dependent. For example, Hands[8] reported 17% reduction in the value of the coef-

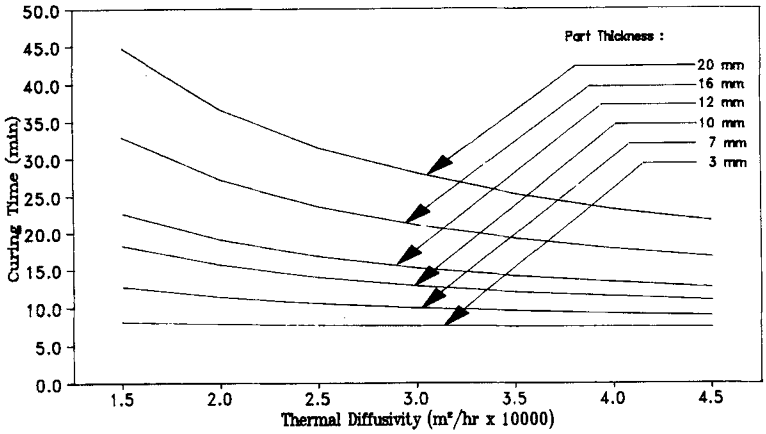

FIGURE 5 Variation of curing time with thermal diffusivity and part thickness.

TABLE III

Programme input data for variation of curing time with bottom plate temperature and part thickness

Thermal diffusivity (m^2/hr)	$3.0e^{-4}$
Temperature coefficient of vulcanisation	1.9
Top plate temperature (°C)	160
Experimental curing time (min)	7
Experimental curing temperature (°C)	160
Initial temperature (°C)	40

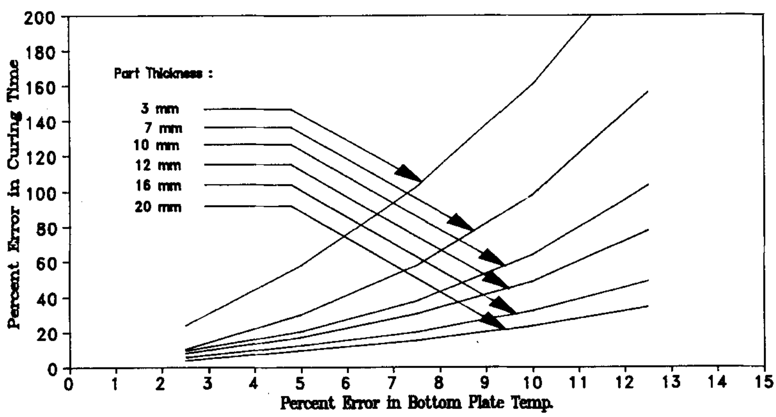

FIGURE 6 Effect of error in bottom plate temperature and part thickness on curing time.

ficient within the temperature range 50 to 200°C, 11% in the range 50 to 100°C, 7% in the range 100 to 150°C and 1% between 150 and 200°C.

In the present study the thermal diffusivity was determined experimentally and assumed independent of temperature. Table II lists input data for determining variation of curing time with thermal diffusivity and part thickness. The results are illustrated in Figure 5 which shows that effect of variation in thermal diffusivity on

TABLE IV

Programme input data for variation of curing time with experimental curing temperature and part thickness

Thermal diffusivity (m^2/hr)	$3.0e^{-4}$
Temperature coefficient of vulcanisation	1.9
Top and bottom plate temperatures (°C)	160
Experimental curing time (min)	7
Initial temperature (°C)	40

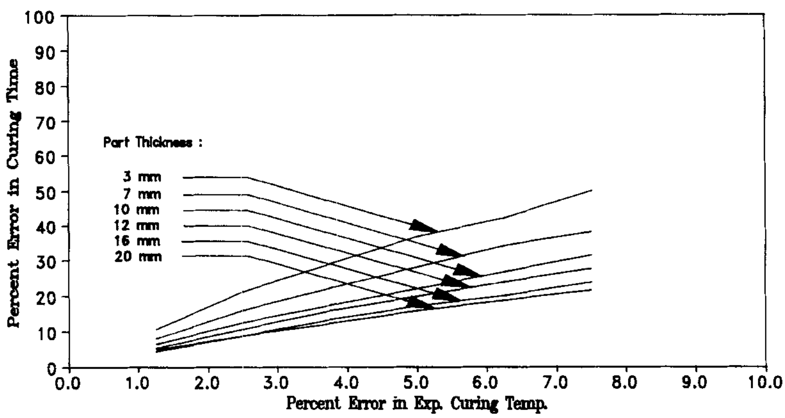

FIGURE 7 Effect of error in experimental curing temperature and part thickness on curing time.

TABLE V

Programme input data for variation of curing time with experimental curing time and part thickness

Thermal diffusivity (m^2/hr)	$3.0e^{-4}$
Temperature coefficient of vulcanisation	1.9
Top and bottom plate temperatures (°C)	160
Experimental curing temperature (°C)	160
Initial temperature (°C)	40

curing time increases with increasing part thickness. The effect is negligible at low thicknesses.

EFFECT OF ERRORS IN THE MEASUREMENT OF ROTO-CURE PRESS TEMPERATURES

By assuming a constant top temperature and varing the bottom temperature of the press, curing times for various thicknesses corresponding to each temperature were computed. Input data are listed in Table III and the results shown graphically in Figure 6. Percent error in curing time is reduced with increasing thickness.

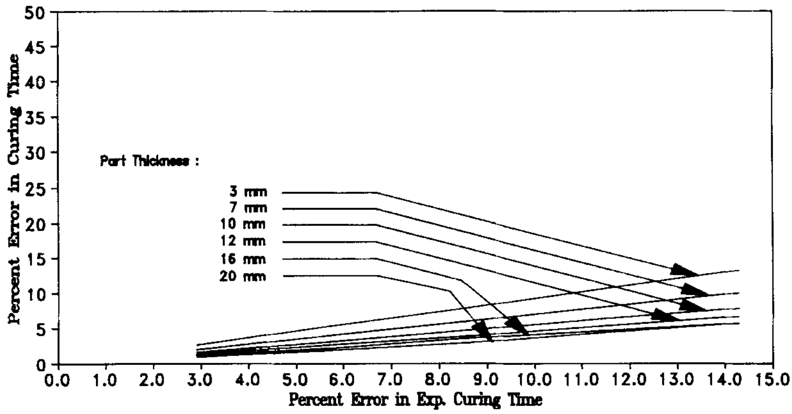

FIGURE 8 Effect of error in experimental curing time and part thickness on curing time.

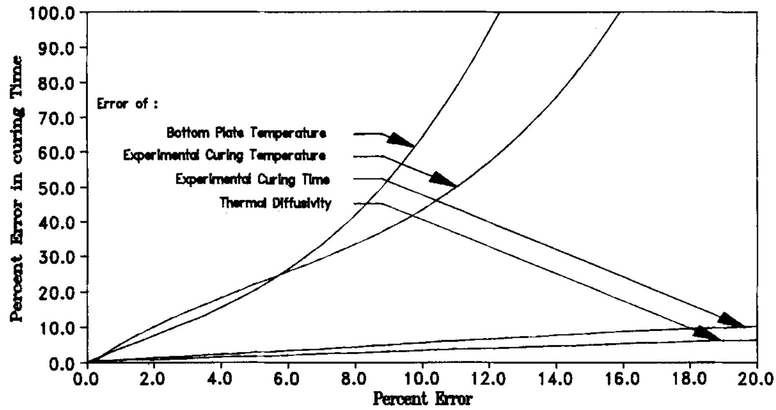

FIGURE 9 Comparison of effect of errors in input data on curing time (belt thickness: 10 mm).

EFFECT OF ERRORS IN THE MEASUREMENT OF EXPERIMENTAL CURING TEMPERATURE

Curing times corresponding to various part thicknesses were evaluated by varying the experimental curing temperature. Table IV shows programme input data. Results are reported in Figure 7 showing a reduction in percent error in calculated curing time with increasing thickness.

EFFECT OF ERRORS IN THE MEASUREMENT OF EXPERIMENTAL CURING TIME

Curing times were calculated for various part thicknesses and experimental curing times. Input data are listed in Table V and the results shown in Figure 8. As before, percent error in calculated curing time is reduced with increasing part thickness.

COMPARISON OF THE EFFECTS OF ERRORS

Figure 9 illustrates a comparison of the effects of errors in various input data on computed curing time for a 10 mm thick conveyor belt. Highest percent of error in curing time is due to errors in the measurement of press temperatures, followed by errors in experimental curing temperature. The effect of errors in the measurement of experimental curing time and thermal diffusivity are insignificant and negligible.

CONCLUSION

Experimentally determined temperature coefficient of vulcanisation is adequate for use in the Sahand computer programme for estimation of conveyor belt curing time. For most purposes this coefficient can be assumed constant and independent of temperature, with a value in the range 1.8 to 1.9.

The assumption of temperature independency for thermal diffusivity is acceptable. At low part thickness the effect of variation of the thermal diffusivity on curing time is negligible. In the absence of information on the actual value, it can be safely assumed from within the range $2.8e^{-4}$ to $3.2e^{-4}$ m^2/hr.

Accurate measurement of the press temperatures and the experimental curing temperature is essential to minimise errors in the computed curing time.

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