

Prediction of Cure Time for a Rubber Cement Used for Conveyer Belt Splicing

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SYNOPSIS

The evolution of bonding strength for a commercial cold vulcanizing rubber cement was determined using small-scale simulated conveyer belt splicing. Peel and shear data obtained under isothermal conditions fit a modified Avrami model $X = 1 - \exp(-kt^{1/2})$, where X is the degree of ultimate shear or peel bond strength obtained and the rate constant k shows a typical Arrhenius type temperature dependence $k = 42 \exp(1670/T) \text{ min}^{1/2}$ for peel strength, and $k = 57 \exp(-2000/T) \text{ min}^{1/2}$ for shear strength. (T is the absolute temperature in K.) Bonding strength evolution under nonisothermal cure conditions can be estimated by integrating the general rate expression $dX/dt = 0.5k^2(1 - X)/(-\ln[1 - X])$.

INTRODUCTION

In the South African mining industry it is common practice to accelerate the curing of cold-vulcanizing rubber cements by using a hot press. This significantly reduces the downtime caused by the replacement or repair of conveyer belts. It is therefore of interest to determine the evolution of bond strength as a function of time and temperature.

When belts are spliced it is also common practice to remove the rubber right down to the carcass. The development of shear and peel strength for a fabric-to-fabric bond is therefore relevant.

EXPERIMENTAL

Peel Strength

Strips of 125 mm wide were cut across the conveyer belt and split lengthwise along the fabric reinforcement so as to expose the fabric surface. These strips were then cut into samples of 300 mm long. The fabric surface was wire-brushed by hand to remove all loose particles. The brushed surface was washed with toluene and the toluene allowed to evaporate

completely (half an hour outside in the sun). A 25-mm-wide strip of masking tape was applied lengthwise along one edge of each sample. The adhesive[†] was mixed in the recommended ratio and applied evenly by brush to the fabric surface. The remaining mixed adhesive was discarded, and the solvent in the adhesive layer was allowed to evaporate for 0.5 h.

A freshly mixed second coat of adhesive was then applied by brush over the first coat. When tack dry, tested by the back of the finger as recommended by the supplier, two of the sample sheets were bonded together with the two strips of masking tape facing each other. The bonded sample was then rolled by hand, placed in the heated press, at the required temperature, at a pressure of approximately 800 kPa. The samples were removed at regular intervals and 25-mm-wide test specimens were cut across the width of the sample.

The test specimens were then immediately placed in a deep freeze at -20°C . The test specimens were removed from the deep freeze and allowed to thaw for approximately 5 min at 23°C prior to testing.

Peel strength tests were conducted at a crosshead speed of 50 mm/min on an Instron tensile testing

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† The adhesive tested is a proprietary formulation sold under the trade name "Rebond" by Rubgen Engineering Supplies, South Africa.

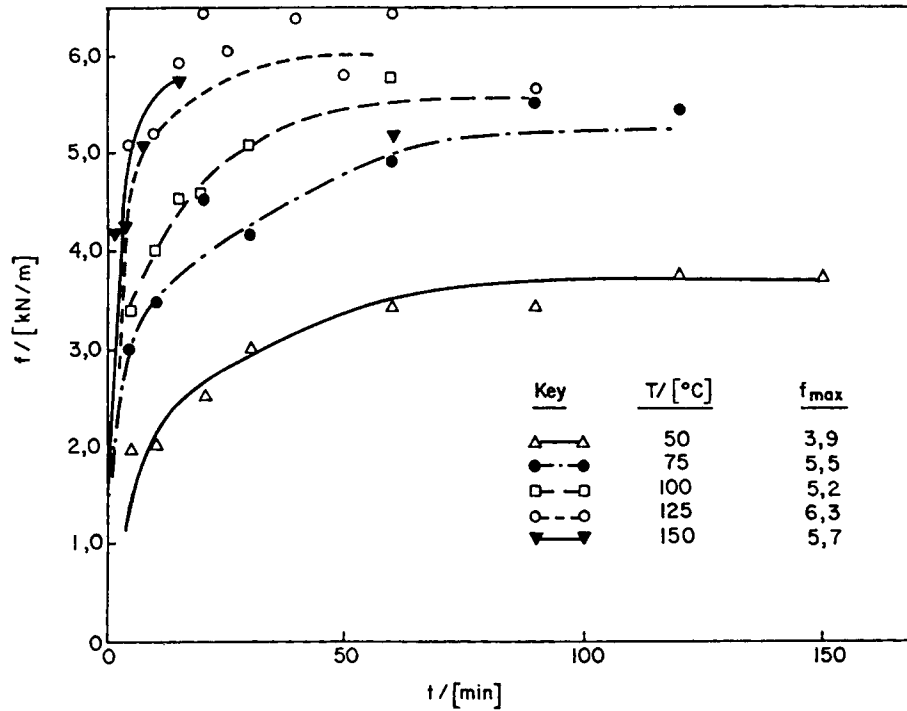


Figure 1 Evolution of peel strength.

machine. A minimum of at least three sets of samples were prepared separately and tested at each temperature.

test specimens having a bonded area of 25 × 25 mm. The testing procedure was as above.

Shear Strength

The samples were prepared as above, except that the bonded area was 25 mm wide. Strips of 25 mm width were cut across this bonded area resulting in

RESULTS AND DISCUSSION

Initial peel and shear strengths, i.e., values measured immediately after rolling by hand were negligible compared to ultimate values. The raw adhesion data

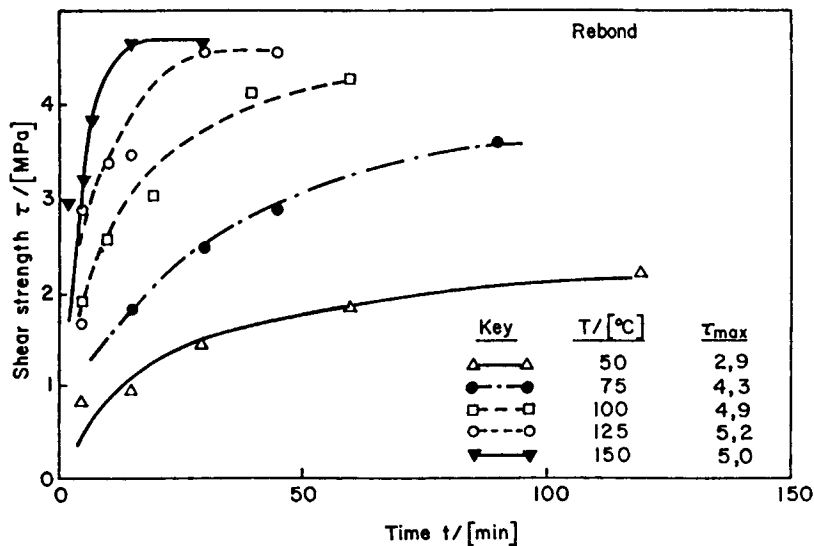


Figure 2 Evolution of shear strength.

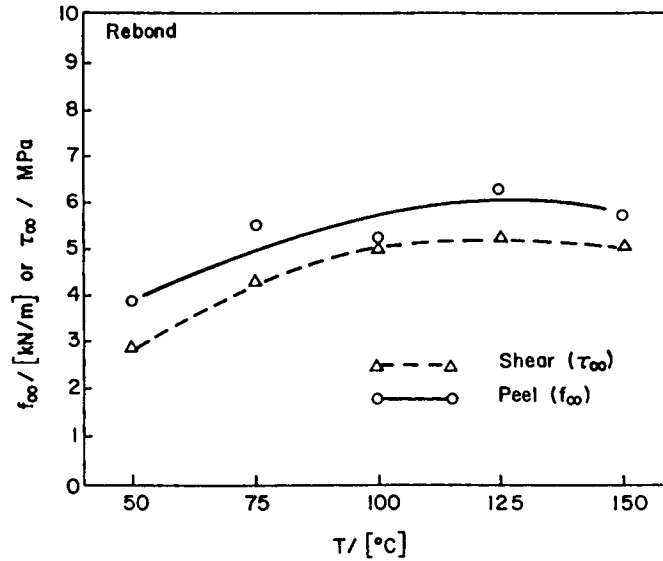


Figure 3 Limiting peel and shear strengths.

are plotted in Figures 1 and 2. Adhesion rapidly rises from a very low initial value and then slowly approaches a limiting value over time. Limiting shear and peel strengths are plotted in Figure 3 as a function of temperature. The limiting values tend to increase with cure temperature but the values for 150°C are somewhat lower. In general, peel strength development is faster than shear strength development.

where f and f_{∞} refer to instantaneous and ultimate peel strengths, respectively.

Best fit to the model [eq. (1)] was obtained with the Avrami exponent having the value $n = \frac{1}{2}$. The temperature dependence of the rate constant is shown in Figure 4. It appears that the k values follow a conventional Arrhenius type dependence

$$k = k_0 \exp(-A/T) \tag{2}$$

Empirical Model of the Curing Process

The time evolution of bonding strength is influenced by a number of complex physical processes:

- plastic flow of the adhesive under pressure and heat to fill microcracks and crevices at the interface (physical bonding);
- chemical curing of the resin to develop mechanical strength in the bulk via crosslinking of chains (cohesive strength) as well as the formation of chemical bonds across the interface (chemical bonding);
- diffusion, adsorption/desorption, and phase separation of residual solvent and adventitious inclusions (e.g., moisture).

Since diffusion coefficients, viscosity, chemical compatibility, chemical cure, etc. are dependent on temperature it has a major effect. The isothermal data fit a modified Avrami equation

$$f/f_{\infty} = 1 - \exp(-kt^n) \tag{1}$$

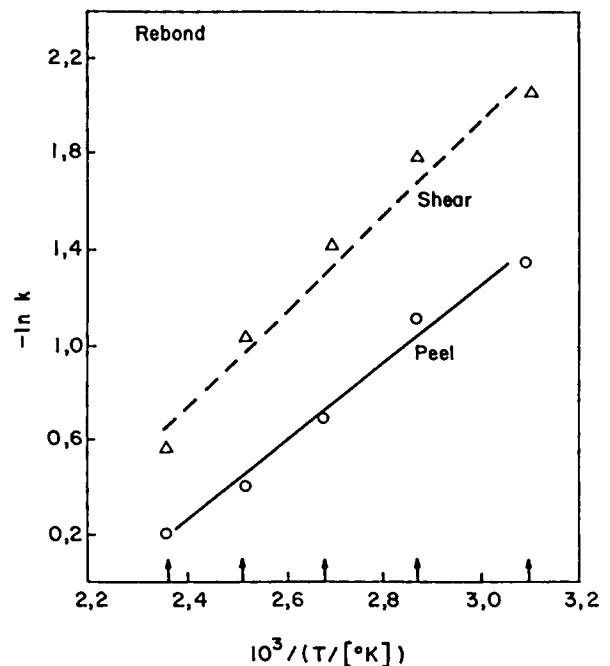


Figure 4 Temperature dependence of the rate constant.

Table I Kinetic Parameters for Rubber Cement

Cure Temperature (°C)	Peel		Shear	
	f_{∞} (kN/m)	k (min ^{-1/2})	τ_{∞} (MPa)	k (min ^{-1/2})
50	3.9	0.25	2.9	0.13
75	5.5	0.33	4.3	0.17
100	5.2	0.50	4.9	0.24
125	6.3	0.66	5.2	0.36
150	5.7	0.81	5.0	0.56
	$k = 42 \exp(-1670/T) \text{min}^{-1/2}$		$k = 57 \exp(-2000/T) \text{min}^{-1/2}$	

where T is the absolute temperature in degrees Kelvin and A is an empirical constant (with the same units) determined by regression analysis of the data shown in Figure 4.

The "cure" parameters are summarized in Table I. In practice curing generally proceeds in a non-isothermal fashion. Equation (1) is an integral form (for isothermal conditions) of the general rate expression:

$$\frac{dX}{dt} = nk^{1/n}(1-X)[-\ln(1-X)]^{(n-1)/n} \quad (3)$$

where X is the degree of cure defined by f/f_{∞} or τ/τ_{∞} .

To determine the evolution of bond strength for arbitrary cure cycles, eq. (3) must be integrated. As-

suming a constant value for f_{∞} (or τ_{∞}), one obtains for $n = \frac{1}{2}$

$$X = 1 - \exp[-(\int k^2 dt)^{1/2}] \quad (4)$$

CONCLUSIONS

The rate of bonding strength development for a commercial rubber cement can be increased by heating. Ultimate bond strength for fabric-to-fabric splices increases with cure temperature up to 125°C. The isothermal data fit a modified Avrami equation with a Avrami exponent of $n = \frac{1}{2}$.

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