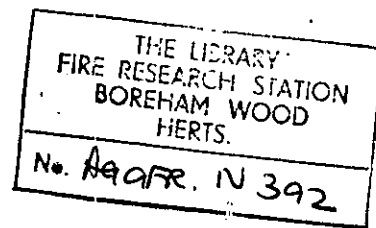


REFERENCE MR Simms

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

THERMAL DAMAGE TO FABRICS AT HIGH INTENSITIES OF RADIATION

by

P. H. Thomas and D. L. Simms

Summary

When the intensity of thermal radiation is greater than a certain value, the total incident energy required to produce the disintegration of a fabric increases with increasing intensity of irradiation, i.e. with decreasing exposure time. This increase in energy has been related to the time lag occurring in the chemical reaction, i.e. the induction period.

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Fire Research Station,
Boreham Wood,
HERTS.

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1. Introduction

Several criteria have been suggested as necessary for the production of different kinds and degrees of thermal damage. The simplest of them is a simple temperature criterion, thermal damage occurring only if the volatiles or solid reaches a certain temperature. This is satisfactory for correlating much of the experimental data on the ignition of materials by radiation (1).

With a fixed temperature criterion, the energy required to produce a given level of thermal damage in a thin material should, with increasing intensity of irradiation, tend towards a limiting minimum value, theoretically independent of the intensity. For thick materials the energy required decreases with increasing intensity. However, at very high rates of heating the induction times of the chemical reactions become significant in relation to the total exposure time, and the simple temperature criterion requires modification because the energy increases with increasing intensity.

In the experiments on ignition carried out at Joint Fire Research Organization where the highest intensity available was about 12 cal/cm²/sec., no significant increase in energies has been obtained, but in some results given by Mixer and Krolak (2) who used a source giving intensities up to 37 cal/cm²/sec¹, there is a well defined increase in energy with increasing exposure time. (Fig. 1). In their experiments, samples of a 9 oz. sateen fabric* were irradiated by a carbon arc source until their opacity disappeared and this paper shows that their results can be interpreted by a thermal model which allows for a chemical induction time.

2. Theoretical analysis

The temperature rise T of a thin fabric irradiated on one face by an intensity I , for time t losing heat from both sides by Newtonian cooling, is given by

$$(T - T_0) = \frac{\alpha I}{2H} (1 - e^{-\frac{2Ht}{mc}}) \dots\dots\dots(1)$$

where T_0 is the initial ambient temperature

- H is the Newtonian cooling constant
- m the weight per unit area
- c the specific heat
- α is the effective absorptivity

For small values of $\frac{Ht}{mc}$ such as occur when the intensity is high, this reduces to

$$(T - T_0) = \frac{\alpha It}{mc} = \frac{\alpha Q}{mc} \dots\dots\dots(2)$$

where Q is the total incident energy.

The rate of production of volatiles is assumed to be first order and to obey the Arrhenius' law.

$$\therefore \frac{\partial \omega}{\partial t} = -f\omega e^{-\frac{E}{RT}} \dots\dots\dots(3)$$

- where ω is the volatile content at time t
- f a frequency factor
- E an energy of activation
- and R is the gas constant

* This has been assumed to mean 9 oz/yd².

Provided $\frac{E}{RT^2} (T - T_0) > 3$ and equation (2) is a valid approximation, equation (3) may be integrated to give the approximate result

$$\text{Log}_e \left(\frac{\omega_0}{\omega_c} \right) \approx \frac{\int e^{-\frac{E}{RT_c}}}{\frac{E}{RT_c^2} \times \frac{dI}{mc}} \dots\dots\dots(4)$$

where ω_0 is the initial concentration of volatiles and ω_c is the final concentration at which damage occurs and T_c is the corresponding temperature. Hence

$$I \propto T_c^2 \exp\left(-\frac{E}{RT_c}\right) \dots\dots\dots(5)$$

The exponential time is much more sensitive to changes in T_c , than is T_c^2 and the T_c^2 term may be treated as constant.

We introduce a temperature T_s nearly equal to T_c and where

$$\frac{E}{RT_s^2} (T_c - T_s) \ll 1,$$

T_s is taken as the temperature at which thermal damage occurs if the induction period were absent. Equation (5) may now be written

$$I \propto \exp\left[-\frac{E}{RT_s}\right] \times \exp\left[+\frac{E}{RT_s^2} (T - T_s)\right] \dots\dots\dots(6)$$

Substituting for T from equation (2) gives

$$I \propto \exp\left[\frac{E}{RT_s^2} \times \frac{dQ}{mc} (T_s - T_0)\right] \dots\dots\dots(7)$$

$$\text{i.e. } \text{log}_e I = \frac{E}{RT_s^2} \times \frac{dQ}{mc} + \text{constant} \dots\dots\dots(8)$$

3. Application of analysis

In fig. 2, $\log I$ is shown plotted against Q for the means of the results by Mixer and Krolak (2) and although the scatter is large, the results lie about a straight line of slope 0.6.

$$\therefore \frac{E}{RT_s^2 \times mc} = \frac{0.6}{d}$$

A value of T_s may be determined from equation (1) using the results for the lower intensities where it may be assumed that only the attainment of a given mean temperature is necessary. These results are quoted below in Table 1.

Table 1

Intensity of irradiation cal cm ⁻² s ⁻¹	Incident energy cal/cm ²	Time of irradiation s
5	19.5	3.9
6	18.0	3.0
7	16.6	2.4

This leads from equation (1) to a value for $\frac{T_s - T_0}{d}$ of 1075°C.

For the values of m , 0.03 g/cm^2 , C , $0.34 \text{ cal g}^{-1} \text{ }^\circ\text{C}^{-1}$ and R , 2 cal/g.mole , this gives values of E between 18,000 and 22,000 cal/g.mole for α between 0.6 and 1. These values are in reasonable agreement with those given elsewhere (3)(4)(5) which range from about 17,000 to 30,000 cal/g.mole.

This analysis has shown, therefore, that the increase in incident energy to produce the same degree of thermal damage with increasing intensity of irradiation although small, about 15 per cent, is consistent with the existence of a chemical induction time. The value obtained for the effective activation energy, E , is reasonable, but because of the uncertainty in α and hence in T_s , no estimate can be made of the effective rate constant 'f'.

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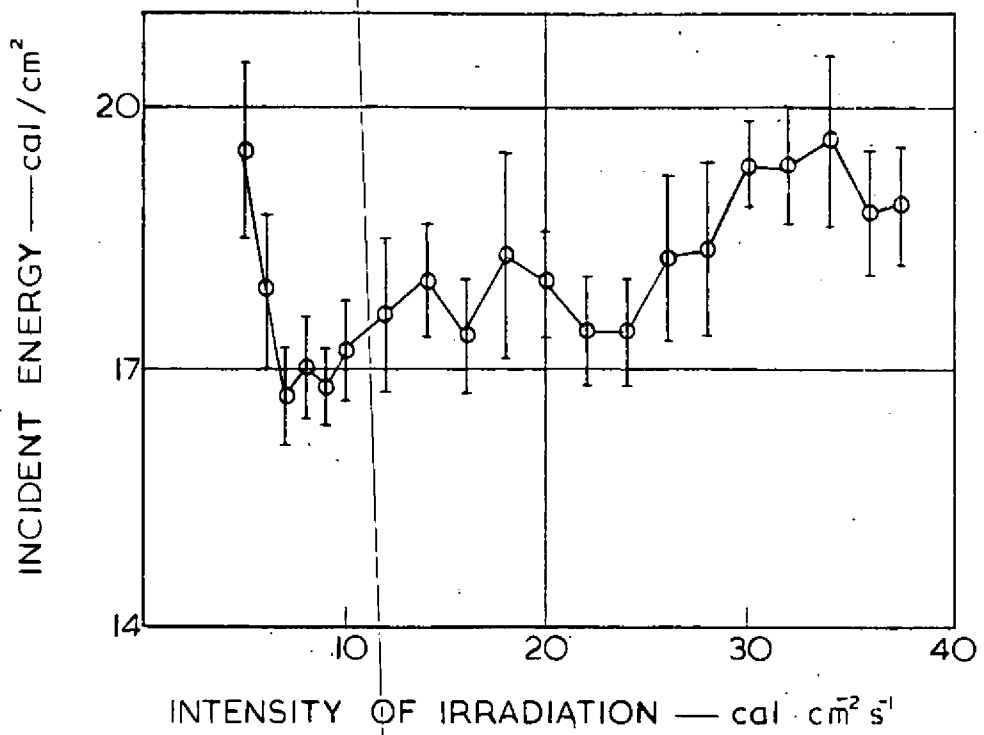


FIG.1. VARIATION OF CRITICAL ENERGY WITH IRRADIANCE (FROM MIXTER AND KROLAK)

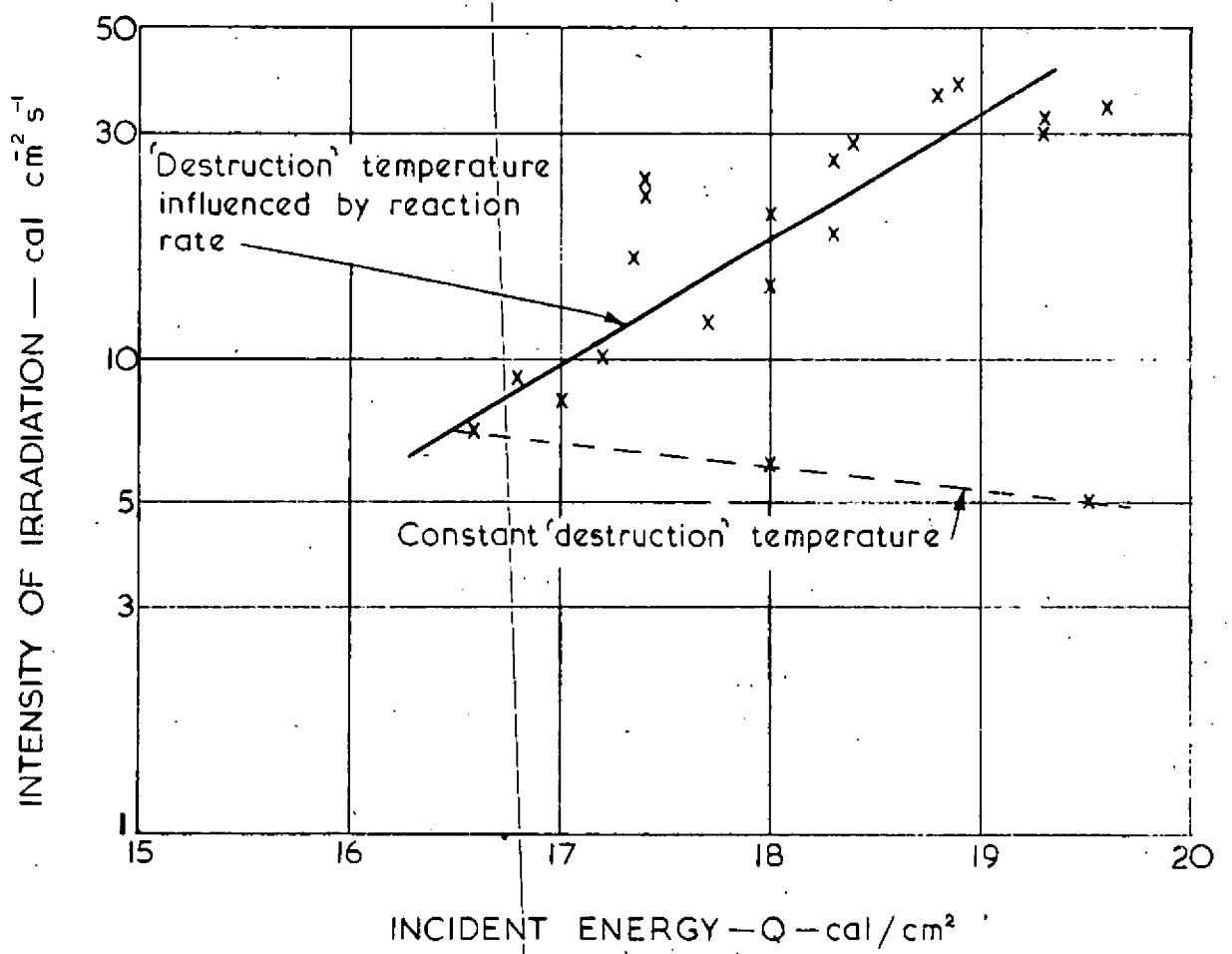


FIG.2. VARIATION OF CRITICAL ENERGY WITH IRRADIANCE