A STUDY ON THERMAL CHARACTERISTICS OF PHASE CHANGE MATERIAL (PCM) IN GYPSUM BOARD FOR BUILDING APPLICATION

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ABSTRACT

Using fatty acids as phase change materials (PCMs), it is possible to store a large amount of thermal energy in a small mass and with a narrow temperature transition. Passive solar heating and cooling can be done by three methods – simple immersion, direct incorporation and encapsulation. This study investigated the effect of using a lauric-stearic acids eutectic mixture at 75.5:24.5 w/w as PCM in gypsum board. The eutectic mixture had a melting point of 34.1°C and latent heat of 171.1 kJ kg^{-1} respectively. Gypsum boards were immersed 1 hr in PCM and the thermal characteristics before and after immersion were investigated. The 12.5 mm board absorbed 38.0% PCM and differential scanning calorimetry (DSC) showed that the melting point and latent heat were 34.0°C and 50.28 kJ kg^{-1}, respectively. For 6 mm board, PCM absorption was 39.2% with the melting point of 34.0°C and the latent heat of 52.87 kJ kg^{-1}. From the results, the thermal characteristics of the PCM-gypsum boards were similar to those of the PCM.

Keywords: eutectic mixtures, fatty acids, latent heat, phase change materials (PCMs), thermal characteristic.

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INTRODUCTION

In PCMs, heat is stored as latent heat of fusion in phase changes. Latent heat allows a large amount of energy to be stored in a small mass/volume with the phase transition occurring at nearly constant temperature. In a wide diurnal temperature range, PCM can be used to absorb heat during the day and release it at night. In hot countries where the temperature is high throughout the day and night, the concept needs to be slightly modified. Otherwise, PCM cannot be used effectively. As an example, a Malaysian terrace house is humid with temperature reaching 50°C in the roof space during a heat wave (Davis *et al.*, 2003). The hot air heats up the concrete structure which retains the heat for most of the day. To achieve a comfortable temperature in the building, the solar heat must be blocked off possibly by using PCM as a barrier with an insulator to prevent heat from entering the building.

For a material to be used as PCM, some of the following criteria must be fulfilled: high heat of fusion, high density, high specific heat, congruent melting, small volume change during phase change, chemical stability, non-corrosive, non-poisonous, non-flammable and non-explosive. Finally, the availability as well as cost should be taken into account (Beghi, 1982).

The selection of PCM has recently been directed towards low melting organic materials to avoid some of the problems inherent in inorganic materials, such as supercooling and segregation. Special attention has been given to fatty acids since they are easily obtained from renewable sources such as oils/fats (Feldman *et al.*, 1996).

Fatty acids show solid-liquid transitions within a narrow temperature range. They are superior to other PCMs in some properties such as melting congruency, chemical stability, non-toxicity and

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melting temperature range for passive solar heating. In the liquid phase, these materials have a surface tension of 20-30 dyne cm^{-1} which is high enough for them to be held in the host material structure. These materials possess elevated latent heats of transition and high specific heats (1.9-2.1 J g^{-1} ºC^{-1}). They also exhibit only small volume changes during melting or solidification (for example, melting dilatation of 0.1-0.2 ml g^{-1}). Fatty acids-based PCMs are chemically and thermally stable and non-toxic with low corrosion activity, and fast colours because of the protected carboxyl group (Feldman *et al*., 1995). PCM can be used alone or in eutectic mixtures (binary mixtures that exhibit fixed melting/ solidification points at a certain ratio between the components and which act as a single component).

In passive solar applications, three methods are proposed for incorporation of a thermal storage material within the construction element: encapsulation of the storage material in high density polyethylene pellets mixed in with gypsum board materials, direct incorporation and simple immersion of conventional boards in molten PCM. The latter method contributes to the economic impact of the passive solar wall (Zelba *et al*., 2003).

In this paper, simple immersion of gypsum boards in a eutectic mixture of lauric-stearic acids (75.5:24.5 w/w) as PCM is discussed. Gypsum is a non-metallic mineral, found as a rock composed of 70.1% calcium sulphate and 20.9% water by weight. In the construction industry, gypsum board is widely used as ceiling, roof and walls. It is considered a good supporting medium for PCM since approximately 41% of it is air voids (Rudd, 1993).

EXPERIMENTAL

Materials

The fatty acids used are lauric acid (99% pure) and stearic acid (98% pure) of commercial grade, products of Palm-Oleo Sdn Bhd, Malaysia. The chemicals were used without any purification. Lauric and stearic acid have melting points of 44ºC and 69.6ºC, respectively. A eutectic mixture of lauric-stearic acids in the weight ratio 75.5:24.5 was prepared by melting the acids together at 80ºC (Sari *et al*., 2004).

In the construction industry, gypsum boards of thickness 6 or 12.5 mm are frequently used and these two thickness types were used in this study. Gypsum board was prepared by mixing gypsum with water in the ratio 1.25:1 and poured into a 20 x 20 x 1.25/ 0.6 cm mould. After stiffening, the boards were cut into 6 x 15 x 1.25/0.6 cm sizes. The physical properties of the gypsum samples before and after immersion in PCM were tested.

Method

The thermal properties of the eutectic mixture of lauric-stearic acids such as melting point, solidification point and latent heat, were first characterized. The gypsum board samples (6 x 15 x 1.25/0.6 cm) were immersed for 1 hr in the eutectic mixture at 60ºC. After immersion, the samples were taken out, dried and their thermal characteristics analysed.

DSC Analysis

Differential scanning calorimetry (DSC Perkin-Elmer Thermal Analysis Seri 7) was used to measure the thermal characteristics of the eutectic mixture and PCM-gypsum boards. Samples (2.5-10 mg) were weighed in a sealed aluminium pan. DSC thermal analysis was performed from –10ºC to +80ºC with a heating rate of 5ºC min^{-1} under a constant stream of nitrogen at atmospheric pressure. The melting temperature of the PCM, T_m, corresponded to the onset temperature obtained by drawing a line at the point of maximum slope of the leading edge of the peak. The latent heat, DH_{fus}, was calculated as the area under the peak by numerical integration. In addition, the melting or solidification peak temperatures were defined as the temperatures of the points from the base line.

RESULTS AND DISCUSSION

DSC analysis of the eutectic mixture of lauric-stearic acids (75.5:24.5 w/w) showed a sharp peak with no secondary peak or hump from –10 to +80ºC. It can be seen from *Figure 1* that the melting temperature, latent heat and melting temperature range of the eutectic mixture were 34.1ºC, 171.1 J g^{-1} and 30.1ºC-42.2ºC, respectively. The melting point of the eutectic mixture was lower than those of the single acids. However, the latent heat was high enough to be comparable to those of other PCMs, such as salt hydrates and polyalcohols, which are 100-250 J g^{-1}. The thermal characteristics of solidification as determined by DSC are shown in *Figure 2* – the solidification point was 30.9ºC, latent heat 168.0 J g^{-1} and solidification temperature range 32.7ºC -23.0ºC. The temperature transitions between melting and solidification were 34.1ºC and 30.9ºC, which are considered close. The solid-liquid phase transition was reversible, as the heat absorbed as latent heat of fusion can be released as the heat of solidification (with a small heat loss).

After immersion for 1 hr in the eutectic mixture, the absorption of acids by the gypsum board did not exceed 30%. Nikolić *et al*. (2003) also reported the absorption not exceeding 30% for some fatty acid esters and a eutectic mixture of palmitic and stearic

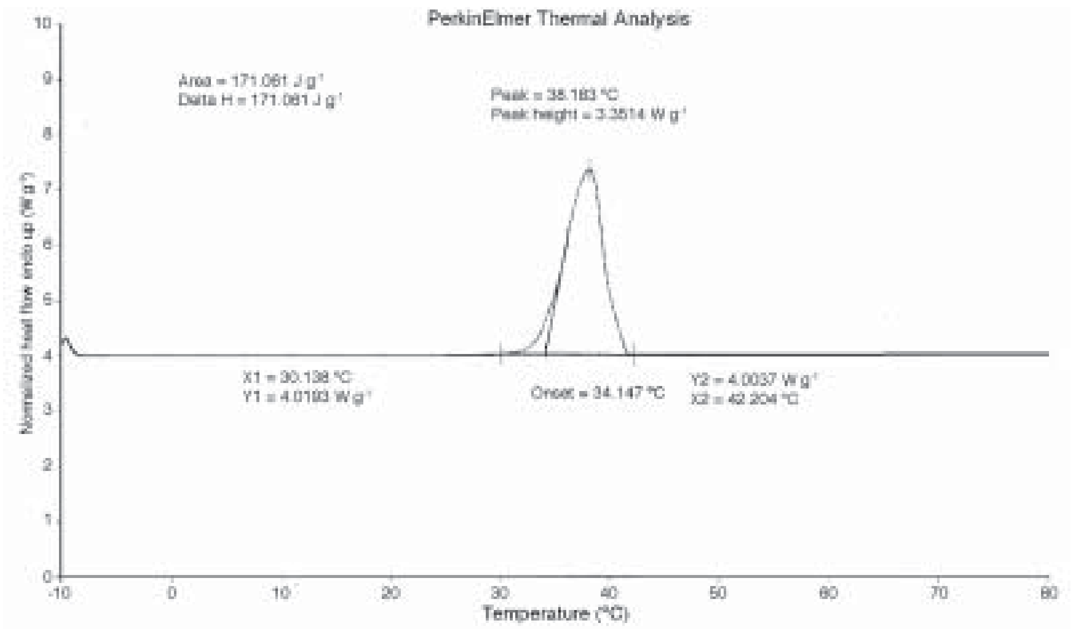

Figure 1. DSC thermogram of the eutectic mixture of lauric-stearic acids (75.5:24.5 w/w) scanned at 5°C min^{-1} (heating).

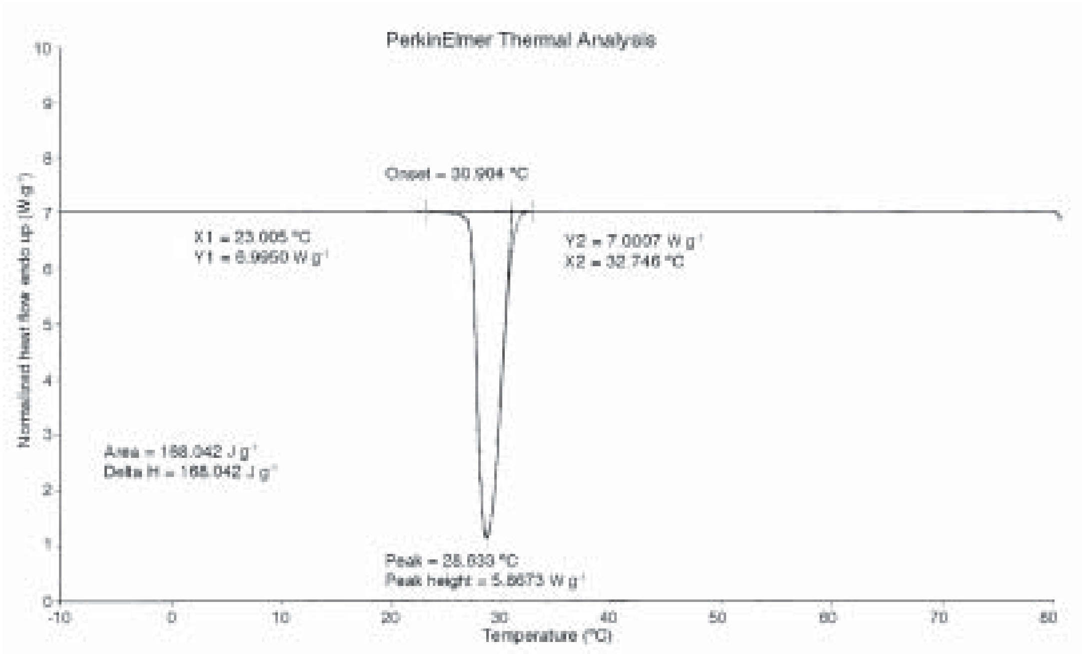

Figure 2. DSC thermogram of the eutectic mixture of lauric-stearic acids (75.5:24.5 w/w) scanned at 5°C min^{-1} (cooling).

acids in the same immersion conditions. Feldman *et al*. (1996) reported only 25% absorption of a eutectic mixture of butyl palmitate-butyl stearate with immersion at lower than 80ºC. The variation on the findings can be due to different immersion times and the type of PCMs used. *Table 1* shows the amounts of fatty acids absorbed by the gypsum boards.

Figures 3 to *6* illustrate the DSC thermograms for the 12.5 mm gypsum board loaded with 27.5% acids and 6 mm gypsum board loaded with 28.2% acids for heating and cooling, respectively. The findings are summarized in *Tables 2* and *3*.

From *Figures 1* to *6*, the thermal characteristics of the PCM-gypsum boards were very close to those of PCM alone. The melting and freezing curves were sharp with no secondary peak or hump.

Some physical properties of the gypsum boards were also tested to show that the immersion did not unduly affect their physical characteristics. Indeed, with the exception of conductivity, which was higher after immersion for better absorption of heat, the

TABLE 1. EUTECTIC MIXTURE ABSORBED BY GYPSUM BOARD (%)

Gypsum board	Replicate 1 (%)	Replicate 2 (%)	Replicate 3 (%)	Average (%)
12.5 mm	28.5	27.5	27.4	27.8
6 mm	26.9	28.2	28.0	27.7

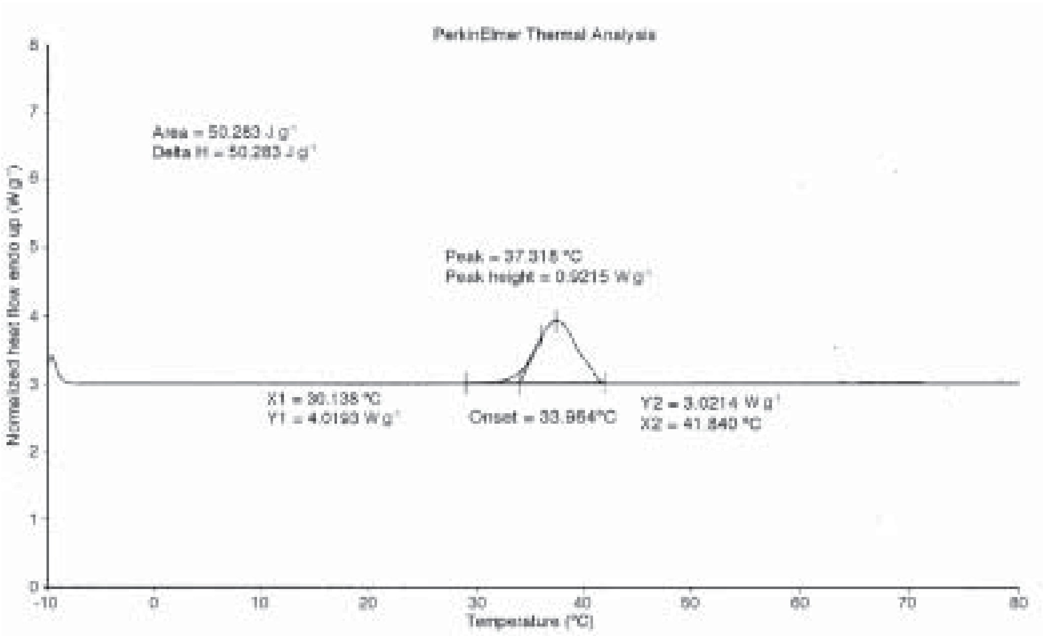

Figure 3. DSC thermogram of the 12.5 mm PCM-gypsum board with loading at 38.0% weight scanned at 5°C min^{-1} (heating).

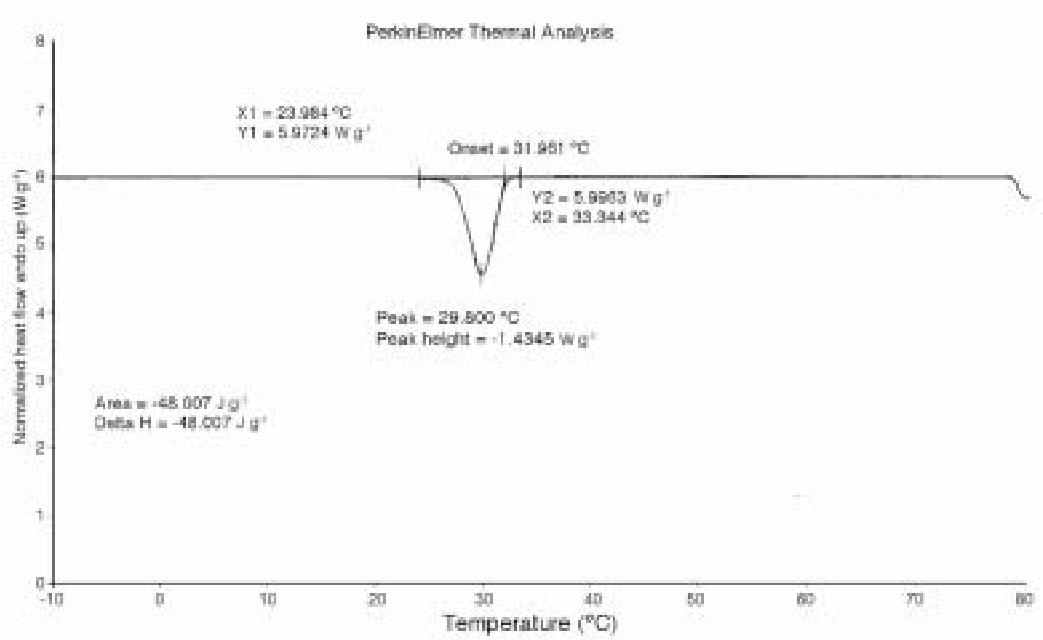

Figure 4. DSC thermogram of the 12.5 mm PCM-gypsum board with loading at 38.0% weight scanned at 5°C min^{-1} (cooling).

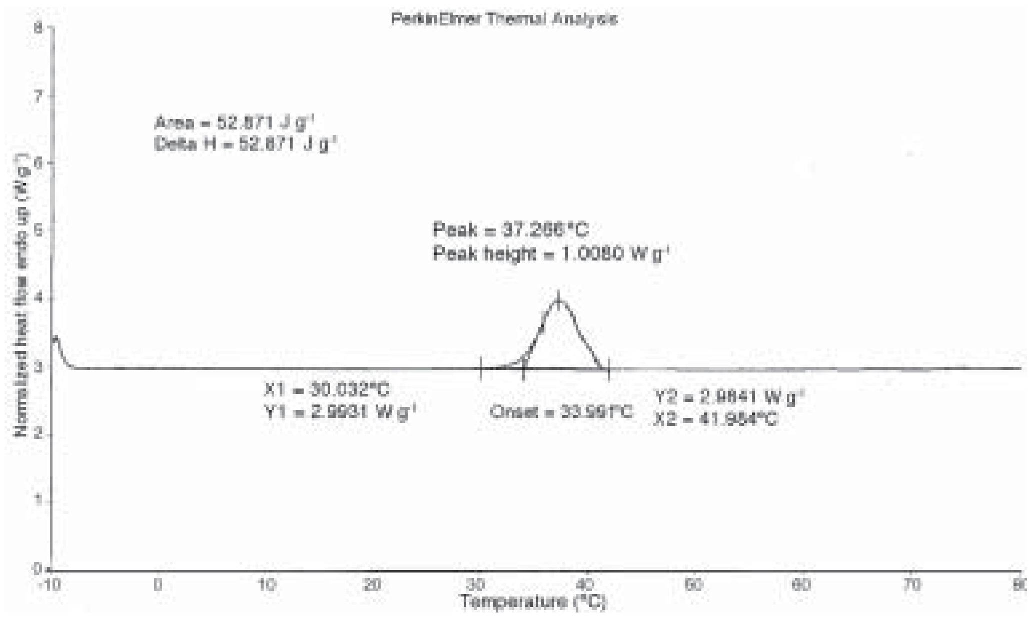

Figure 5. DSC thermogram of the 6 mm PCM-gypsum board with loading at 39.2% weight scanned at 5ºC min^{-1} (heating).

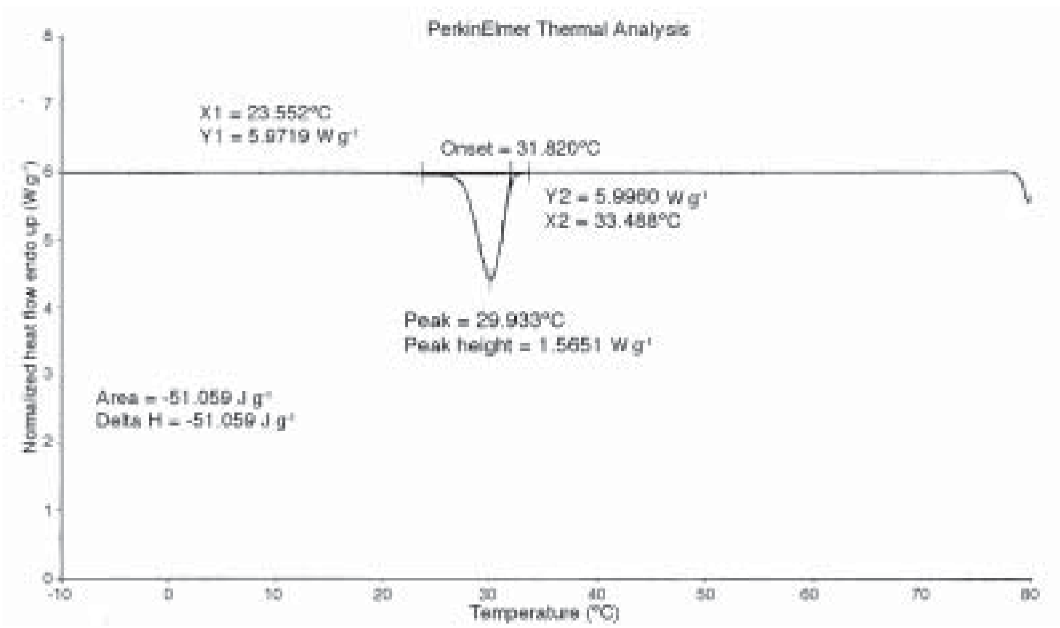

Figure 6. DSC thermogram of the 6 mm PCM-gypsum board with loading at 39.2% weight scanned at 5ºC min^{-1} (cooling).

TABLE 2. THERMAL CHARACTERISTICS OF THE PCM-GYPSUM BOARDS (melting)

Gypsum board	Replicate	Melting point T_m (°C)	Latent heat ΔH_{fus} (J g^{-1})	Melting temperature range (°C)
12.5 mm	1	34.1	55.96	30.9-42.3
	2	34.0	50.28	28.9-41.8
	3	33.9	55.68	29.7-41.8
6 mm	1	34.3	46.60	31.6-42.1
	2	34.0	52.87	30.0-42.0
	3	33.8	55.24	28.6-42.3

TABLE 3. THERMAL CHARACTERISTICS OF THE PCM-GYPSUM BOARDS

Gypsum board	Replicate	Melting point T_m (°C)	Latent heat ΔH_{fus} (J g^{-1})	Solidification temperature range (°C)
12.5 mm	1	32.4	54.43	34.4-23.7
	2	32.0	48.01	33.3-24.0
	3	32.2	53.63	33.5-22.0
6 mm	1	32.2	45.36	33.5-24.0
	2	31.8	51.06	33.5-23.6
	3	32.0	52.93	33.8-23.8

TABLE 4. PHYSICAL PROPERTIES OF GYPSUM BOARDS BEFORE AND AFTER IMMERSION

Gypsum board	Conductivity at 31°C (W m^{-1} K^{-1})		Density (kg m^{-3})		Shore hardness	
	Before	After	Before	After	Before	After
12.5 mm	0.4937	0.5632	957.2	1498.9	85	85
6 mm	**0.3871**	**0.4940**	**957.8**	**1447.6**	**87**	**86**

PCM did not decrease in hardness. The different thickness of gypsum also did not affect the absorption of acids and the thermal characteristics. *Table 4* shows some physical properties of the gypsum boards before and after immersion.

CONCLUSION

The eutectic mixture of lauric-stearic acids (75.5:24.5 w/w) had a melting point of 34.1°C, heat of fusion of 171.1 J g^{-1} and close temperature transition. When impregnated in gypsum boards, the thermal characteristics of the mixture were practically unchanged, with one sharp peak and no additional peak or hump. Indeed, the immersion did not affect the physical characteristics of the gypsum boards. For further study, it is recommended that a suitable insulator be attached to the PCM-gypsum board and an accelerated thermal cycle test run to detect any thermal behaviour change (if any) in long-term use.

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