THERMAL RESPONSE OF A TIRE SHRED-SOIL EMBANKMENT

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Abstract: A full-scale embankment divided into three sections (tire shreds mixed with soil, tire shred layered with soil and a soil-only section) was monitored for a period of 18 months with the objective to evaluate the potential factors influencing internal heating. The monitoring program evaluated methods to prevent exothermic reactions in embankments utilizing tire shreds and to contribute to the development of design guidelines for future tire shred applications. The analysis conducted on the collected data shows that mixing or layering tire shred with soil minimizes the potential for exothermic reactions from occurring within a tire shred reinforced embankment. It is also shown from this analysis that precipitation does increase exothermic reactions within a tire shred-only stockpile, but does not necessarily affect the heat generation within the tire shred-soil embankment or the internal temperature within the structure.

INTRODUCTION

Nearly 250 million tires per year are added to the 2 billion tires that already exist in landfills in the United States (Edil and Bosscher, 1994). Civil engineers have tackled the issue of developing environmentally sound and aesthetically pleasing alternatives to tire disposal by proposing use of tires in civil engineering projects including retaining structures, backfill and road sub-grade. The technical issues involved with these applications range from tire shred and tire bale mechanical properties to the thermal properties of tires that can potentially trigger exothermic reactions with the structures.

Despite the positive mechanical properties that tire shreds provide when used as lightweight backfill, there have been documented cases of internal exothermic reactions in tire shred embankments that ultimately led to failure of the project. The most prolific of these cases include SR 100 in Il Waco, Washington; Garfield County, Washington and Glenwood Canyon in Colorado where flames were observed within the tire shred backfills. Research has identified potential factors influencing these reactions; however, the cause of exothermic reactions within tire shred embankments has not been confirmed. This research approaches the problem of exothermic reactions in civil engineering applications by evaluating design approaches that are expected to *prevent* these heat generating reactions. Specifically, this research will attempt to prove that, when mixed or layered with soil, tire shreds do not experience an exothermic reaction.

The primary objective of this research is to define design recommendations through the evaluation of the thermal response of different embankment layouts using tire shreds that may prove to be viable alternatives to the current design guidelines. In addition, this research is intended to show that these approaches minimize the potential for exothermic reactions in civil engineering applications utilizing tire shreds as backfill material. Other objectives to be accomplished through this research include the following: determine thermal properties of tire shreds, soil and tire shred/soil combinations; determine the effect of precipitation on the internal

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temperature within an embankment; and determine potential factors influencing exothermic reactions within a tire shred embankment.

BACKGROUND

Potential Causes of Exothermic Reactions. Exothermic reactions within a tire shred embankment precede ignition or combustion of tire shreds, which ultimately lead to failure through excessive settlement and open flames. The current understanding of the mechanisms that cause exothermic reactions is inconclusive; however, available data does identify possible factors that contribute to exothermic reactions within tire shred fills. These identified causes include: oxidation of exposed steel wires, microbes generating acidic conditions, microbes consuming the exposed steel belts, oxidation of the tire rubber, and/or microbes consuming liquid petroleum products (Humphrey, 1996).

Embankment Design. A tire shred-soil embankment was constructed for this project consisting of three sections each approximately 30 feet long, 5 feet deep and 30 feet wide. The three sections include a soil-only section, a mixed section and a layered section. The mixed section consists of 10% tire shreds by weight and the layered section consists of three one foot layers. All three sections have a final 12-inch layer of soil that acts as a driving surface.

Instrumentation Plan. The instrumentation plan was designed in order to evaluate the potential causes of exothermic reactions. The identified variables were measured in the different embankment sections at three different depths, in addition to being monitored in a tire shred-only stockpile. The measured parameters included the following: temperature, soil moisture, relative humidity and heat flux. These variables were measured every fifteen minutes with the hourly average recorded in a central datalogger. The recorded values were downloaded on a regular basis either by laptop or through remote access using a wireless modem.

RESULTS AND ANALYSIS

Temperature Observations. The internal temperature within all three embankment sections followed both diurnal and seasonal trends with the higher temperature occurring over the summer. The temperature fluctuated more at the shallower thermistor depth; however, the temperature fluctuation did not necessarily coincide with the fluctuations of the ambient temperature. There appeared to be a time lag between the peak air temperature during a 24-hour period and the peak internal temperature, possibly due to heat transfer occurring within the embankment. The internal temperature was also compared with the ambient temperature to determine if there was a correlation. This is shown in Figure 1a, which shows the temperature in the mixed section and is representative of the other two sections. It can be seen that there is an increasing linear relationship at each depth. The error bars indicate that the internal temperature is generally within $\pm$20°F of the ambient temperature. The best-fit linear trend line indicates a slope of one and a negative intercept, indicative of a direct relationship between the ambient temperature and the internal temperature. The negative intercept suggests that the internal temperature is generally lower than the ambient temperature. This trend along with the trendline slope of one suggests that the embankment dissipates the heat transferred from the atmosphere at a continuous rate. For the large tire shred-only stockpile the trendlines had slopes greater than one and the intercept were not all negative, as shown in Figure 1b. A slope greater than one implies that as the ambient temperature increased, the internal temperature increased at a great rate, indicative of another heat source or internal heat generation with the tire shred-only stockpile.

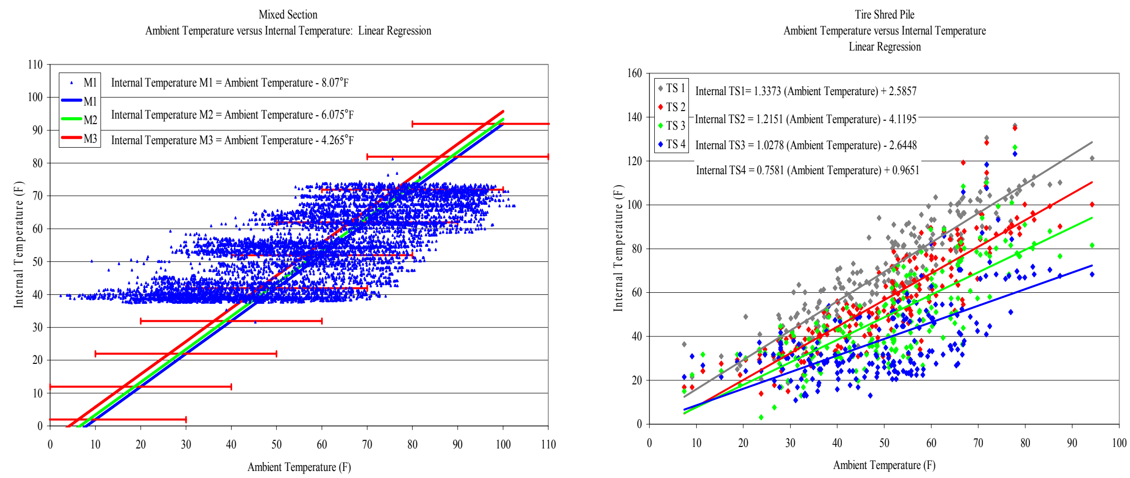

Fig. 1. Linear Regression of Ambient Temperature versus Internal Temperature

a) Mixed Section b) Tire Shred-Only Stockpile

Time Periods. In order to analyze the temperature and heat generation trends within the embankment and tire shred-only stockpile, six time periods were selected to analyze. Three of these time periods were during times of relatively constant temperature and three were identified where the daily average temperature showed an increase. The three time periods of relatively constant temperature were during periods of no rainfall and the three with increasing temperature trends were identified as being directly following a precipitation event.

Thermal Conductivity. The heat transfer occurring during the time periods of constant temperature, or dry time periods was assumed to be through pure conduction. Through the relation between the thermal diffusivity, density and mass heat capacity of the embankment, the thermal conductivity for the three embankment sections and tire shred stockpile was determined. These values were 1.14, 1.23, 1.44 and 0.33 Btu/hr·ft·°F for the soil only, layered, mixed and tire shred stockpile, respectively.

Heat Generation Analysis. The heat generation within each of the tire shred-soil embankment sections and the tire shred-only stockpile was determined by a finite difference evaluation. The governing differential equation for conductive heat transfer within a solid, with heat generation that cannot be accounted for by the conduction is represented as (Carslaw and Jaeger, 1959):

$$q + k\frac{\delta^2 t}{\delta z^2} = \rho C \frac{\delta T}{\delta t}$$

Where "q" equals the heat generation in Btu/ft^3-hr. The value of "q" for each of the time periods and embankment sections was determined using the thermal conductivity determined previously and using the finite difference method. The following table summarizes the average heat generation rates for the "dry" and "wet" time periods and embankment sections.

Table 1: Heat Generation Rate

Time Period	Soil Only (Btu/ft^3/day)	Layered (Btu/ft^3/day)	Mixed (Btu/ft^3/day)	Tire Shred Stockpile (Btu/ft^3/day)
Dry Average	-49.3	-49.6	-42.9	43.9
Wet Average	-59.0	-54.3	-49.8	62.6

This table presents the average value of the heat generation rate within the embankment sections for both the "dry" and "wet" time periods. It is important to notice that the heat generation within the tire shred-soil embankment sections are negative, indicating an endothermic reaction; whereas, within the large tire shred-only stockpile the reactions were exothermic (i.e. positive). These results provide evidence that when tire shreds are either layered or mixed with soil they are less likely to experience an exothermic reaction in either dry or wet conditions than a large stockpile of pure tire shreds. These results also show that there appears to be a correlation between the rainfall and the heat generation within the tire shred only stockpile.

The heat generation determined throughout the six different time periods was compared with the other monitored variables to determine if any correlation existed that might provide further confirmation of the potential causes of exothermic reactions within tire shred embankments. The only correlation determined was between the heat generation rate and the measured soil suction. The comparison of the heat generation rate and the soil suction determined that as the soil suction decreases (i.e. as moisture increases), the heat generation increases. This correlation is consistent with potential causes of exothermic reactions, such as oxidation of the steel belts, which are expected to be facilitated by the presence of moisture.

CONCLUSIONS

The observation of the internal temperature and the heat generation analysis validated that either mixing or layering tire shreds with soil minimizes the potential for exothermic reactions from occurring with an embankment. The endothermic reactions within the tire shred-soil embankment sections were in clear contrast to the exothermic reactions in the tire shred-only stockpile. This shows that one of the most crucial elements in designing a layout for tire shred reinforced embankments is the amount of isolated tire shreds. The results from this analysis also showed that precipitation or external moisture does increase the exothermic reaction within the tire shred-only stockpile; and, that increases in internal soil moisture in the embankment sections also increases the heat generation rate. This correlation with moisture is in accordance with the hypothesis that the greater the moisture, the more conducive the environment for the potential causes of exothermic reactions, such as oxidation of the steel belts. The significance of these findings is primarily the confirmation that tire shreds can be used in civil engineering applications without having major concerns of exothermic reactions.

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