DRY RANGE AND WET RANGE MOISTURE CONTENT OF ROOFING MATERIALS AS FOUND IN EXISTING ROOFS

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Knowledge of the moisture content of existing roofs is crucial for three reasons:

1. Moisture above normal within the roof structure indicates areas of undesirable moisture entry and a degree of roof failure.
2. Increased moisture in itself deteriorates roofing materials.
   a. In organic felt membranes, moisture causes tensile strength loss[1] and contributes to blister formation, ridge formation and splitting.[2, 3, 4]
   b. In many insulations, moisture causes the loss of physical integrity.
3. Increased moisture within roofing insulation substantially decreases the thermal insulating efficiency.[5, 6, 7]

MOISTURE ABSORPTION CHARACTERISTICS

Materials used in the construction of built-up roofs differ in composition and as a result have individual and distinctive characteristics in relation to their ability to absorb moisture.

The moisture-absorption characteristics of roofing materials have been studied in the laboratory under conditions of high humidity and also when completely immersed in water.[8, 9, 10] The laboratory studies have established a distinct range of moisture content for each individual roofing material, which varies from near zero to maximum absorption at saturation.

The laboratory studies have established an equilibrium moisture-absorption range for each type of roofing material in contact with ambient air. Table 1 lists the weight percent of moisture absorbed by roofing materials when exposed to air in a controlled 90 percent relative humidity environment. This moisture content approximates the maximum moisture absorbed from ambient air for each material. Table 1 also lists the maximum moisture absorbed when each roofing material is immersed in water until no further weight gain takes place. This is saturation.

The question remains: what are the ranges of moisture content of roofing materials as found in the real world of roofs existing in the field and how do they compare to the values obtained from laboratory studies?

DISCUSSION

Over a period of nine years, approximately 1,600 core samples from existing roofs have been examined. The core samples are 2¼ inches in diameter. The core samples were selected randomly from roof areas believed to be dry and randomly from areas believed to be wet-based on roof moisture survey data. Moisture content was determined gravimetrically for both membrane and insulation using a sensitive analytical balance with an accuracy of ±0.01 milligrams. (A gravimetrically determined moisture content of a core sample is the *average* moisture content of the sample.) The studies indicate that moisture frequently is not uniformly distributed throughout the insulation sample (*Figure 1A*). Conductance probe tests in the field and laboratory indicated that many of the insulation samples were wetter on the bottom than on the top. Also, the reverse moisture stratification was observed, wetter at the top, drier at the bottom (*Figure 1*). Since the percent moisture content obtained by gravimetric analysis is the *average* of the wet and dry portions of the sample, the moisture content of specific layers of the insulation can contain a substantially higher or lower moisture content than the *average* readings obtained from gravimetric analysis of the total core.

DATA TABULATION

Moisture content frequency histograms have been developed from the roof core data for a number of commonly used roofing materials. The histograms indicate the relative frequency of occurrence of specific increments of moisture content. Figures 2, 5, 7 and 12 cover the full moisture content range of rigid urethane, organic felt membrane, perlite board, and lightweight concrete, respectively. All of the roofing materials studied indicated full-range moisture content frequency patterns similar to the four examples shown.

The moisture frequency occurrence at the drier end of the moisture content range is examined more closely by developing frequency histograms with smaller and smaller increments of moisture change. The change in perspective obtained by this procedure is illustrated by comparing Figure 2, Figure 3, and Figure 4 for urethane. Figure 2 illustrates moisture content increments of 50 percent and covers the total moisture absorption range. In Figure 3, the increments have been reduced from 50 percent to 5 percent and covers the range from 0 percent to 50 percent. In Figure 4, the increments have been reduced to 1 percent and covers the range from 0 percent to 25 percent.

Figure 4 gives a close look at the moisture variation present within the least wet area of the total moisture content range. Figure 4 indicates the existence of a central tendency and the development of a slightly skewed bell curve distribution pattern within the 1 percent to 7 percent range which is essentially hidden in the full range histograms of Figure 2 and Figure 3. The 1-percent-to-7-percent-dry range distribution pattern compares very well with the 0 percent to 6 percent ambient range predicted from laboratory studies of Urethane insulation exposed to 90 percent relative humidity air. (*Table 1*)

A similar moisture frequency pattern is illustrated by comparing Figure 5 and Figure 6 for organic felt membrane.

Figure 5 illustrates moisture content increments of 1 percent and covers the full moisture content range obtained from the core samples. In Figure 6 the increments have been reduced to 0.1 percent and covers the range of 0 percent to 5 percent. The membrane moisture content histogram exhibits a bell curve distribution pattern similar to urethane but in the range of 0.1 percent to 1 percent. This dry range pattern fits the predicted 0 percent to 1 percent dry range calculated for the composite built-up organic felt membrane,[10, 11] based on moisture absorption studies of roofing felts at 90 percent relative humidity.

One percent increment moisture content histograms with a range of 0 percent to 25 percent for additional commonly used roof insulations are illustrated in Figures 8, 9, 10, 11 and 13. A central tendency and bell curve distribution pattern within the low moisture content range was found to exist for all materials studied. The range of the bell curve distribution pattern exhibited by the histogram of each material at the low end of the moisture content range conforms closely to the range predicted from the laboratory studies in which laboratory samples were exposed to conditions of 90 percent relative humidity.[10, 11] *(Table 1)*

Mean values have been calculated from the distribution patterns exhibited at the low end of the moisture content range for each material and are recorded in Table 2.

While the histograms exhibit the formation of a mode within the dry range, there is little indication of mode formation as the samples become wetter. The moisture frequency occurrence becomes increasingly random and no bimodal character is developed. This generally would not be the case if all of the core samples were obtained from one roof. When frequency histograms are developed from data obtained from nondestructive moisture detection sensors in which many determinations are made for a single roof, bimodal and even trimodal frequency patterns frequently develop, but both test methods indicate greater randomness in the wet range.

The maximum and minimum moisture content obtained from the field core samples are listed in Table 2. The maximum moisture content found in field samples generally conforms to the saturation moisture percentages obtained in the laboratory by immersion and listed in Table 1.

SUMMARY

The moisture histogram patterns obtained from field core samples indicate that two distinct sample populations exist within a roof.

1. A dry range population controlled by reaching moisture equilibrium with ambient air.
2. A wet range population controlled by the amount of liquid water which has entered the roof structure.

The dry range moisture content controlled by ambient air is narrow and distinctive for each roofing material. The moisture content in the dry range is never zero, but varies from a minimum equilibrium moisture content to a maximum equilibrium moisture content at approximately 90 percent relative humidity which is dependent upon the specific absorption characteristics of the roofing material. The dry moisture content range obtained from studies of existing roofs conforms very well to the range expected from laboratory studies.

Wet range moisture content is controlled by contact with liquid water from roof leaks or dew point condensation. The moisture content frequency distribution within this range varies widely. The moisture content range is different for each material. A greater frequency of occurrence is indicated at the lower end of the scale and there is less frequency of occurrence at the higher end of the scale. Considering the common use of the term "saturated" within the industry, less than 0.01 percent of the total sample population tested actually approached true saturation.

The meaning of moisture content within a roof structure is greatly enhanced when the distinct and individual dry range and wet range absorption characteristics of each roofing material are understood.

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Type Material	Equilibrium Moisture Content at 90% RH 75°F	Maximum Moisture Content* Obtained by Immersion
Organic Felt Membrane	1.0%	20%
Fiberboard	12.0%	430%
Perlite Board	4.0%	580%
Glass Fiber	2.0%	610%
Urethane	6.0%	520%
Expanded Polystyrene	3.0%	540%
Lightweight Concrete	6.0%	110%
Dry Asphaltic Fills	0.1%	60%
Cellular Glass	0.01%	30%
Extruded Polystyrene	0.5%	10% to 15%

*Potable surface water at room temperature
References for Table 1.[8, 9, 10, 11, 12]

Table 1 Laboratory moisture studies of roofing materials moisture content percent by weight

Type Material	Dry Range Histogram Mean	Lowest Moisture Content Core	Highest Moisture Content Core
Organic Built-Up Membrane Sample Size 607	0 to 1% range mean = 0.54% 0 to 2% range mean = 0.75%	0.15%	28%
Fiberboard Sample Size 184	0 to 10% range mean = 7.02% 0 to 15% range mean = 7.83%	3.8%	480%
Perlite Board Sample Size 249	0 to 6% range mean = 3.32% 0 to 10% range mean = 3.78%	0.39%	533%
Glass Fiber Sample Size 166	0 to 4% range mean = 1.84% 0 to 10% range mean = 2.74%	0.64%	580%
Urethane Sample Size 160	0 to 7% range mean = 3.96% 0 to 10% range mean = 4.4%	1.30%	552%
Expanded Polystyrene Sample Size 73	0 to 10% range mean = 7.41% 0 to 15% range mean = 8.9%	5.29%	2,446%
Lightweight Concrete Sample Size 74	0 to 10% range mean = 6.14% 0 to 15% range mean = 7.07%	2.95%	114%
Dry Asphaltic Fills	*	0.81%	74%
Cellular Glass	*	0.58%	3.1%
Extruded Polystyrene	*	No Samples	No Samples

*Due to limited samples histograms of Foamglas, dry asphaltic fills and extruded polystyrene are not included.

Table 2 Field core moisture data moisture content percent by weight

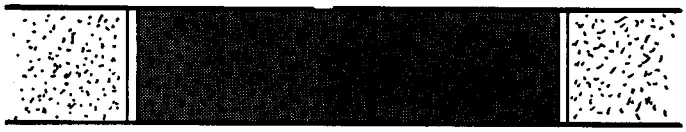
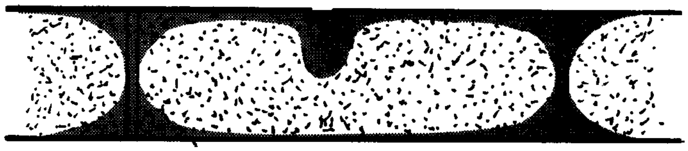


Figure 1a



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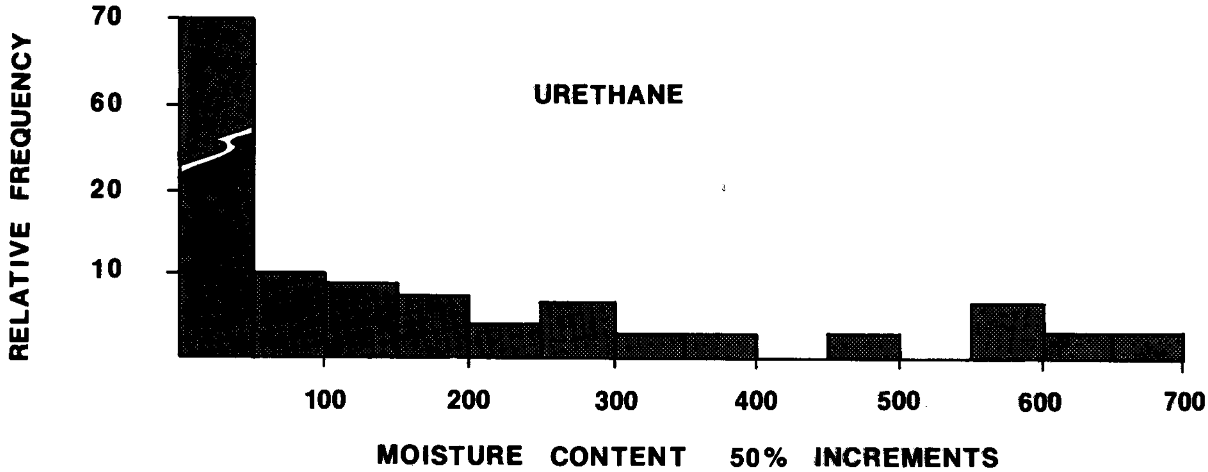
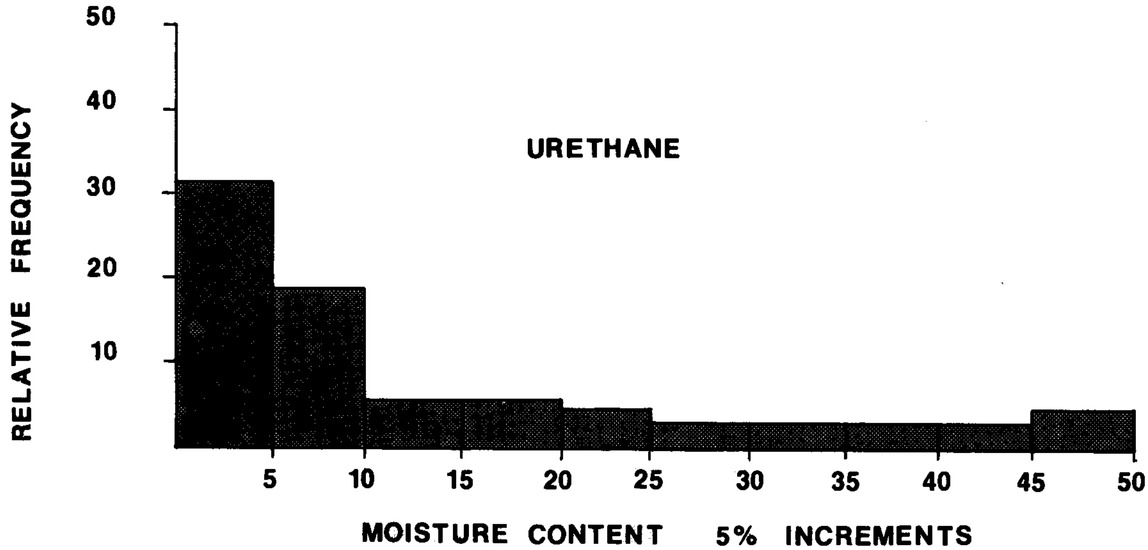


Figure 2



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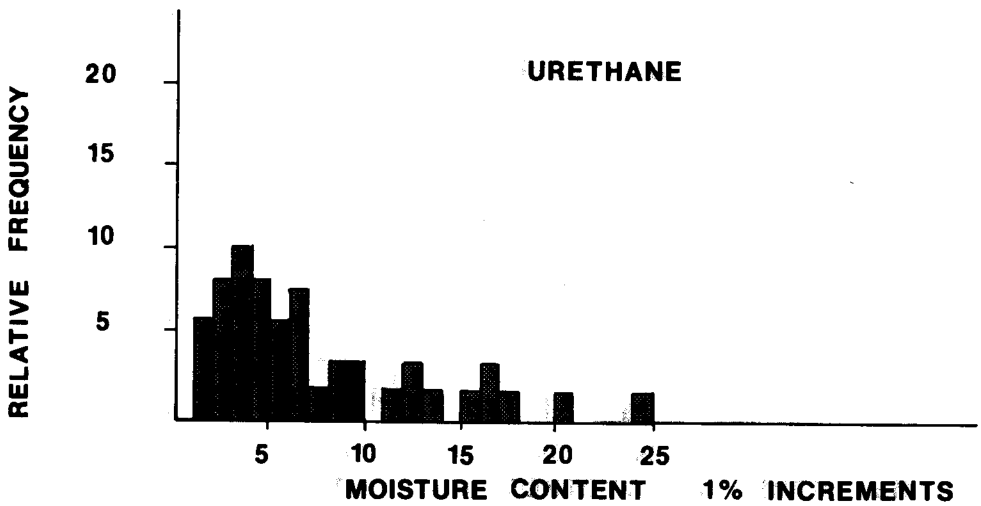

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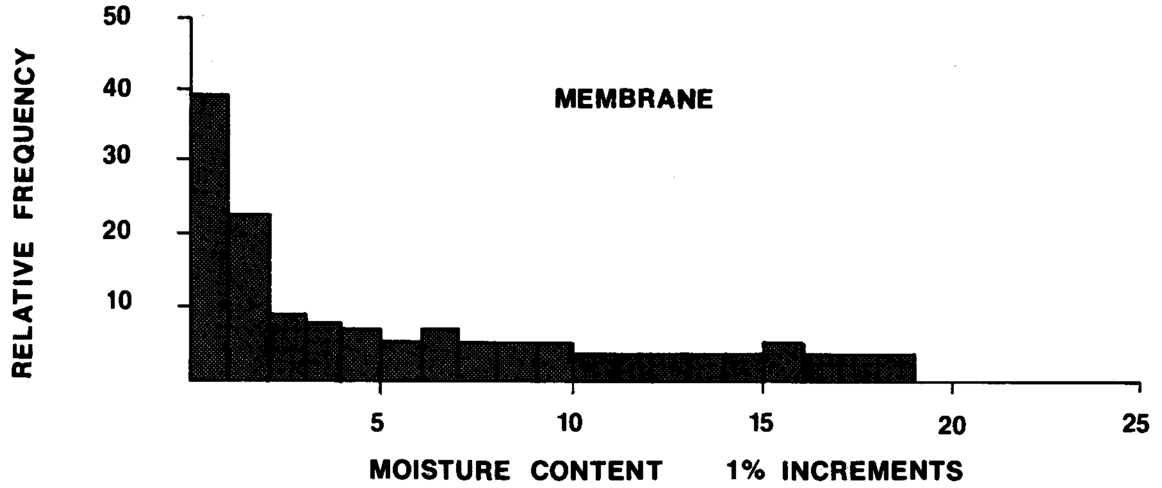


Figure 5

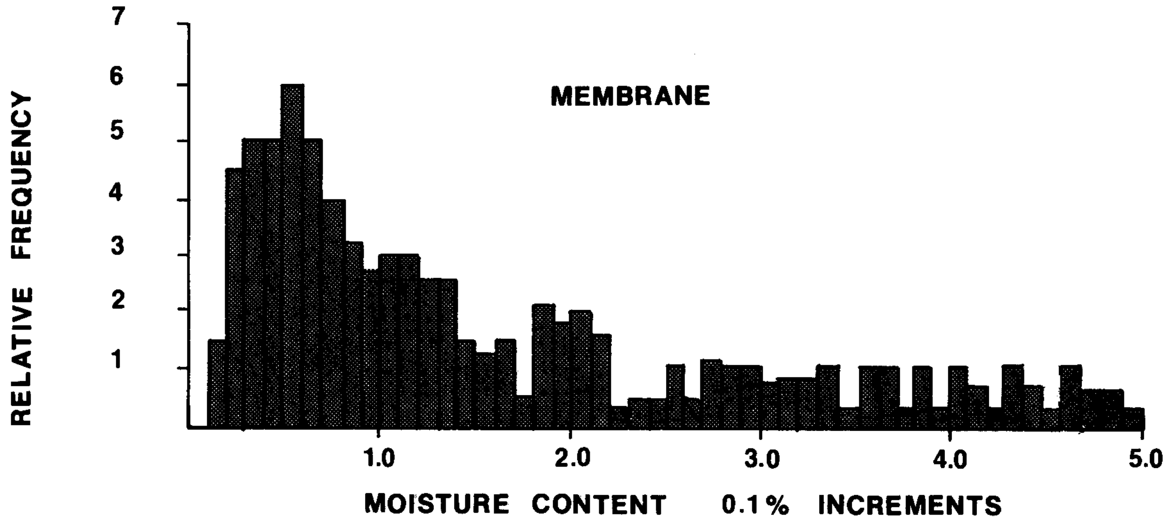


Figure 6

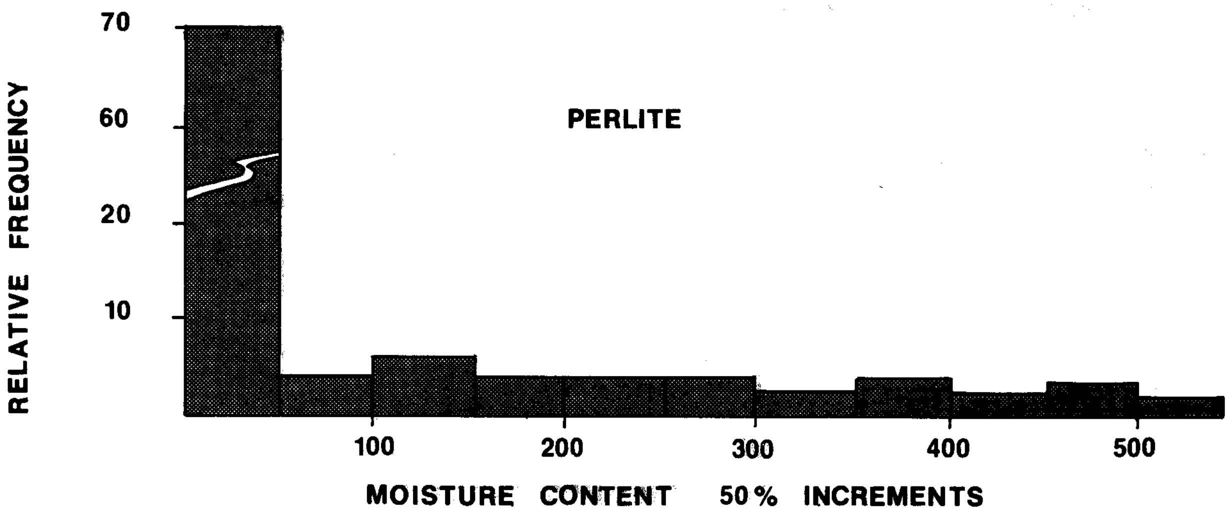


Figure 7

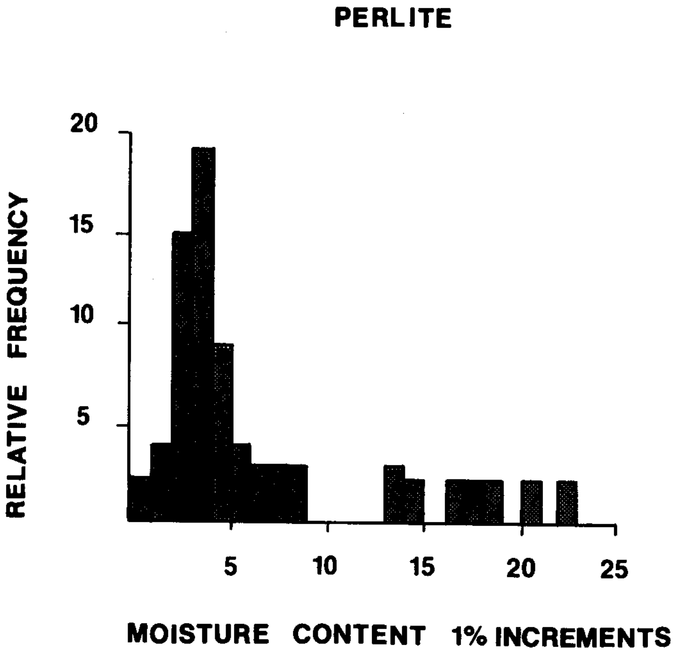


Figure 8

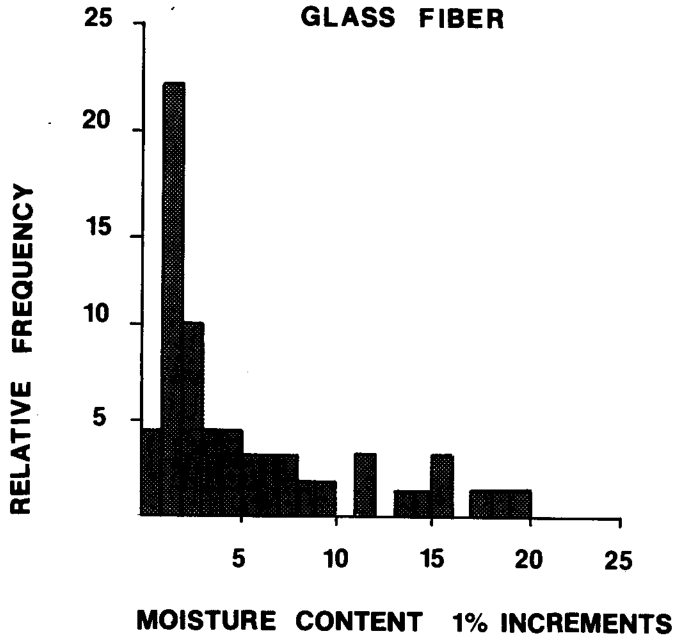
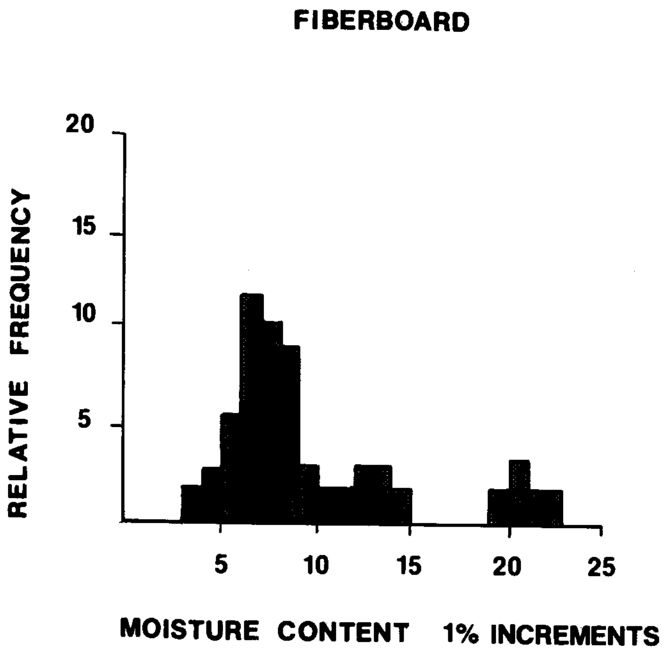


Figure 10



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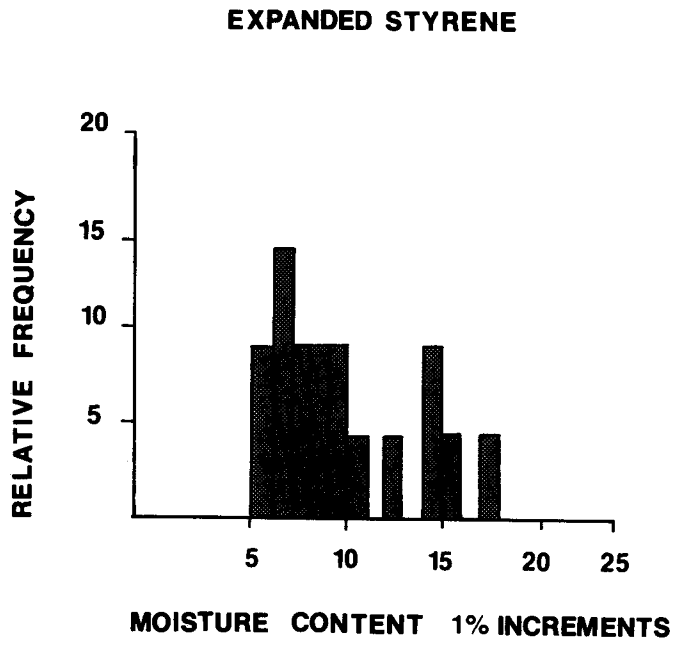

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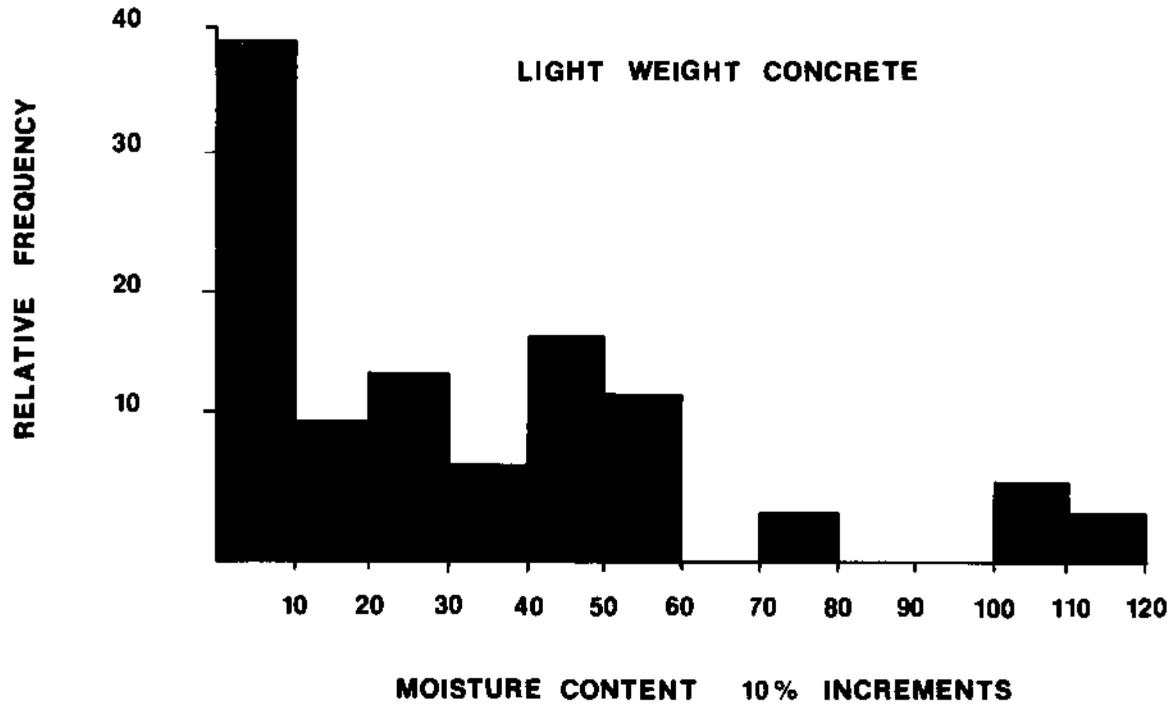

Figure 12

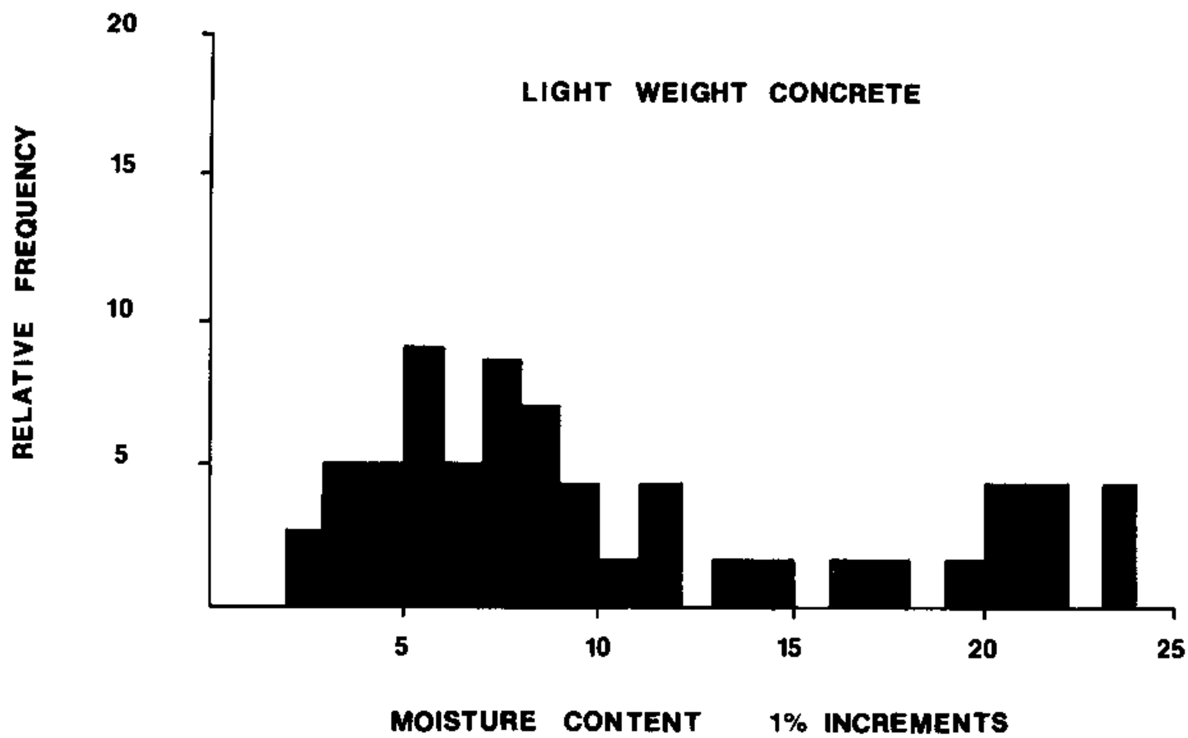

Figure 13