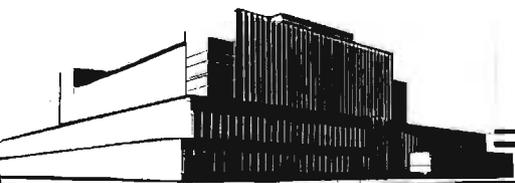


THERMAL EXPANSION OF FREE FILMS OF HOUSE PAINT

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THERMAL EXPANSION OF FREE FILMS OF HOUSE PAINT

By

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Abstract

Free films of house paints of either oil type or emulsion type expand and contract with change in temperature more markedly than wood does, just as was previously found to be the case for change in moisture content. Disruption of coatings comes more from stresses developed within the coatings themselves than from differences in movement between wood and coating.

Introduction

For a long time, allegedly excessive dimensional movement of wood with change in temperature or in moisture content commonly has been held accountable for the disruption of house paints and other coatings (1, 2, 12, 13)². A colorful example appeared in the house organ (October 1959) of a maker of paint vehicles, to the effect that wood has "rather poor dimensional stability," that it "shows a phenomenal degree of expansion," and that its "expansion and contraction across the grain is murder on paint films."

Data often are reported for the thermal expansion (1) or moisture swelling of wood (12), but the tacit assumption of less movement of the paint film is left unsupported by factual observations. The few investigators who have measured the thermal expansion (10) or moisture swelling (5, 8, 10) of paint films find that films of customary house paints undergo greater movement, often much greater movement, than wood does. Any difference in movement between paint coating and wood surface, of course, puts stress chiefly on the coating, which usually is weaker because it is much thinner than the wood; still, some of the consequences of the stress would be expected to differ according as the wood or the coating undergoes the greater movement.

There is greater movement in width of flat-grain boards than of edge-grain boards when temperature or moisture content (14) changes. In softwoods the dense summerwood bands move more than the light springwood bands. Thus the earlier disruption of paint coatings on flat-grain than on edge-grain surfaces, and on summerwood than on springwood, might be attributed to stress applied by wood if wood movement exceeded paint movement. Discovery that paint movement usually exceeds wood movement casts serious doubt on the theory that disruptive stresses originate in wood movement.

¹Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

²Underlined numbers in parentheses refer to literature cited at the end of this report.

Movement of wood in softwood surfaces undergoing change in moisture content has been examined in detail (6). Wood movement with change in temperature follows a similar pattern. In flat-grain surfaces summerwood, because it is bound in the tangential direction to the springwood, moves only slightly more than the springwood. The small difference in wood movement could scarcely account for the conspicuously earlier disruption of coatings on the summerwood bands even if wood movement exceeded coating movement, and certainly cannot do so when the coating moves more than the wood does. In edge-grain surfaces, where the movement of the summerwood is unrestrained, wood movement is maximum in the summerwood and minimum in the springwood. Moreover, in the direction normal to the edge-grain surfaces there is a marked difference in movement of springwood and summerwood that tends to bend a coating sharply. Edge-grain surfaces, therefore, impose greater and more diverse stresses on paint coatings than flat-grain surfaces do, yet it is the edge-grain surfaces that hold coatings intact longer.

Elm (11) reported that the occurrence of cracks in paint coatings in a direction parallel to the grain of the wood, often attributed to the greater movement of wood across than with the grain, in fact is due to the customary practice of making the last brush strokes parallel to the grain of the wood. When the paint is stroked last across the wood grain the cracks in the coating likewise occur at right angles to the wood grain. The grain of the paint, produced by orientation of acicular pigments, determines the direction of cracking independently of wood movement. Elm's finding agrees with many observations by the Forest Products Laboratory on its test fences and on houses. Likewise, when paint coatings become unduly thick from too-frequent repainting, the direction of cracking commonly shifts to the cross-grain direction (9).

Hess (13) said: "Good outdoor paints rarely crack due to working of the wooden base under normal conditions because the wood maintains a more or less constant moisture content. That is, however, different in a very dry climate. There peeling, etc., of paint films due to intense shrinkage of the wood is quite frequent (see fig. 60). If, of course, --the application was made on to, perhaps, abnormally moist wood, then under such conditions, deterioration of outdoor coatings, due to the behavior of the wood, will take place. The same is also possible under normal climatic conditions."

Hess greatly underestimates the changes in moisture content of wood on houses. His fig. 60 shows the disruption of a lead-zinc house paint on flat-grain white fir exposed on the Forest Products Laboratory's test fence at Tucson, Ariz., for 2 years (1924-1926). Later tests at Tucson showed distinctly improved durability of three kinds of oil paint when the wood (ponderosa pine) was sponged thoroughly with water a few minutes before the first coat of paint was applied. The effects of moist and of dry wood were compared on adjacent parts of the same flat-grain boards. Abnormal moisture in the wood at the time of painting proved beneficial, but its effect can hardly be attributed to subsequent movement of the wood.

In both wood and paint coatings much greater movement results from changes in moisture content than from any change to be expected in temperature. Thus a film of titanium-zinc oil paint that swells in area 36.6 percent when soaked in water expands in area only 3.2 percent when its temperature is raised 100° C. Corresponding values for white lead oil paint are 2.7 percent when swollen in water and 1.3 percent when warmed 100° C.

Although the swelling of films of house paint in water and damp air has been examined in detail (5), few data have been published on the thermal expansion of paint films. Dunn (10) reported observations of eight linseed oil house paints tested both before and

after exposure to the weather for 6 months. The pigmentation of the paints and their age when tested initially were not disclosed. Expansion was measured in but one direction of the films, presumably in the direction of the grain of the paint. Temperature was raised from room temperature to about 20° C. above it in 3 hours. Linear coefficients of expansion for the films before weathering ranged from 81×10^{-6} to 196×10^{-6} and after weathering from 40×10^{-6} to 93×10^{-6} .

To obtain more detailed data for the thermal expansion of free paint films, a series of experiments were made at the Forest Products Laboratory. For comparison purposes the thermal expansion of western redcedar, a softwood of low density and low expansion, and of Douglas-fir and southern yellow pine, softwoods of high density and high expansion, are reported in table 1. The data were calculated from the information in the Wood Handbook (14) except that the specific gravity of the springwood and summerwood of southern yellow pine is from Browne (7).

Experimental Procedure

The oil paints and alkyd-resin paint used were made at the Forest Products Laboratory. The symbols expressing paint composition in tables 2 to 6 have the following meanings: L, basic carbonate white lead; Z, zinc oxide (lead-free, acicular type); T, titanium dioxide (rutile type); Tx, a mixture of titanium dioxide and extending pigment (usually 1 part of the former to 3.2 parts of magnesium silicate by volume); A, antimony oxide; and X, magnesium silicate. Subscripts to letter symbols give the percentage by volume of the referenced pigment in the total pigment. Symbol "p/nv 0.30" shows, for example, that the total pigment amounted to 0.30 of the total nonvolatile matter (pigment plus nonvolatile vehicle) in the paint. The nonvolatile vehicle in the oil paints was unbodied linseed oil with lead and manganese naphthenate drier. The nonvolatile vehicle of the alkyd-resin paint was a commercial product widely used for "blister- and stain-resistant" paints. The emulsion paints and the primers made for use with them were commercial products of large manufacturers for all of which the label formulas are recorded in the book of original record.

Paints were applied on clean tinplate by doctor blade. After standing in the laboratory for 9 to 11 days for the coatings to dry thoroughly, one set of films was stripped from the tinplate by amalgamation with mercury. A second set was exposed to artificial weathering for 15 days. The exposure was to the sunlight spectrum from a flaming carbon arc enclosed in Corex D glass and to spraying with distilled water three times an hour. After weathering, the films were stripped from the tinplate by amalgamation.

For testing, films were cut into circular specimens 8.2 centimeters in diameter. Each film was marked to show the direction of the paint grain. Two parallel datum lines were then drawn approximately 7.5 centimeters apart and at right angles to the paint grain. The distance between the datum lines, measured precisely with a traveling microscope, was taken as the length, L, of the film. Two more datum lines were drawn similarly 7.5 centimeters apart and parallel to the grain direction. The distance between the second pair of datum lines was the width, B, of the film.

For precise measurement of length and width at controlled temperatures, a film was floated on mercury held in a glass crystallizing dish, 10 centimeters in diameter by 5 centimeters deep. A small brad was first glued, pointed end up, at the center of the bottom of the crystallizing dish. A copper-constantan thermocouple also was fastened

to the inside bottom of the dish with pressure tape. A layer of dry mercury about 5 millimeters deep was then placed in the dish. The film to be measured was skewered at its center on the brad and floated on the mercury. Thus the center of the film was fixed in position while the film remained free to move radially in response to change in temperature. Rotation about the brad was prevented by skewering a piece of writing paper, about 7 centimeters in diameter, on top of the paint film. The brad held the paper firmly and slight friction between paper and paint film kept the film from turning. Mercury wets paint films enough to keep them perfectly flat.

Temperature was controlled with water jackets made of half-gallon friction-top paint cans. Circular holes cut in the friction tops were of a diameter just sufficient to admit the crystallizing dish and yet engage its beaded rim. Three water jackets were provided--one for a mixture of ice and water at 0°C ., one for water at room temperature, which was approximately 21°C ., and one for warm water at approximately 55°C . The cold and the warm jackets were insulated on their outer walls with 2 centimeters of glass fiber insulation covered with paper.

Immediately after the crystallizing dish was inserted in a water jacket, the dish was covered with a transparent, moisture-impermeable plastic film to keep any moisture evaporating from the water jacket from gaining access to the paint film. Each paint film was weighed on an analytical balance before and after a cycle of measurements to ensure that it had not changed in moisture content. Temperature of the mercury under the paint film was measured by the thermocouple, the leads from which went to a potentiometer that was carefully calibrated over the range of temperature of the experiments. The jacketed dish with its contents was mounted under a traveling microscope capable of reading to 0.0001 centimeter. When constancy of temperature was assured, the length of the film was measured by 10 successive transits of the microscope, the jacket was rotated 90 degrees, and the width of the film was measured by 10 more microscope transits.

Measurements recorded in tables 2, 3, and 4 always were made in the following order: Room temperature, 0°C ., 55°C ., room temperature. About 1-1/2 hours were required to complete the measurements of a single paint film, which involved 80 microscope transits, numerous potentiometer readings, time to reach constancy after each change in temperature, weighing, mounting, and reweighing the film. The temperature coefficients reported in tables 2 and 3 are for the rising range of temperature from 0° to 55°C . The coefficients in table 4 are for the declining ranges of temperature from 21° to 0°C . and from 55° to 21°C . The unweathered films were measured when about 10 days old and again after standing in the laboratory until they were well over a month old.

Results and Discussion

Linseed-Oil Paints

Table 2 reports the coefficients of thermal expansion in length, width, and area for films of 10 linseed-oil paints of differing pigmentation. The coefficients were smaller for white lead paint, L_p/nv 0.30, than for any other linseed-oil paint, and they changed very little as the film aged or weathered. The coefficients for linear expansion were nearly equal to the tangential coefficient for southern yellow pine or Douglas-fir (table 1). For expansion in area, however, the coefficients for white lead paint were

nearly double that for flat-grain southern yellow pine. The coefficients for all other linseed-oil paints in table 2 significantly exceeded those for white lead paint. For paint TxZ₁₇ p/nv 0.26, for example, the expansion in area of the 10-day-old film was nearly 5 times and that of the weathered film more than 3-1/2 times that of flat-grain southern yellow pine.

Except for white lead paint, the films of linseed-oil paints expanded appreciably less when they were aged for a month, and still less when they were weathered, than they did when about 10 days old.

The paints that possessed distinct grain because of orientation of acicular pigments during application proved anisotropic in thermal expansion, just as they were found previously to be anisotropic in moisture swelling. Paints made entirely with effectively spherical pigments such as white lead, titanium dioxide, and antimony oxide were nearly isotropic (ratio of expansion across the grain to expansion with the grain between 0.8 and 1.2); nearly all other paints, which contained at least one acicular pigment, proved distinctly anisotropic with the ratio $\Delta B/\Delta L$ ranging from 1.4 to 2.7. In such cases the expansion across the paint grain always exceeded the expansion with the grain. The paints TxZ₁₇ p/nv 0.26 and TxZ₁₇ p/nv 0.475, for which the anisotropy was relatively low, contained somewhat more than the 3.2 to 1 proportion of extending pigment to titanium dioxide. Furthermore, this extending pigment consisted of a less markedly acicular grade of magnesium silicate together with a substantial proportion of calcium carbonate, which is effectively spherical.

Comparison of the films of paint TxZ₁₇ p/nv 0.475 with those of paint TxZ₁₇ p/nv 0.26 suggests that higher pigment loading significantly decreases thermal expansion. Presumably the volumetric expansion of the oil vehicle exceeds that of the pigment particles, as might well be expected. The thermal expansion may be minimum at the critical pigment volume, as was previously reported for moisture swelling (4).

Varnish-Vehicle and Emulsion Paints

Table 3 shows that, for films of the titanium alkyd-resin paint Tx(ar) p/nv 0.30, the coefficients of thermal expansion were smaller than those of films of linseed-oil paints T p/nv 0.30 and X p/nv 0.30, but they were much greater than those for films of white lead paint. The ratios $\Delta B/\Delta L$ for paint Tx(ar) p/nv 0.30 were similar to those for paint TxZ₁₇ p/nv 0.26, presumably because the extending pigments in the two paints were very similar.

The commercial primers of oil type made for use with emulsion house paints (table 3) made films with thermal coefficients of expansion comparable in magnitude with those of the mixed-pigment linseed-oil paints. Brand B primer was reported to contain titanium dioxide and aluminum silicate pigments in a linseed alkyd-resin vehicle, but its rapid drying indicated a much shorter oil alkyd-resin than that in paint T(ar) p/nv 0.30. Oil-type primer of brand D was said to contain titanium dioxide, white lead, barium sulfate, and magnesium silicate in a "tung and linseed oils, rosin" vehicle.

Emulsion primer of brand D was said to be pigmented with titanium dioxide, white lead, silica, and silicates in a "modified linseed alkyd" vehicle (emulsified in water). All three emulsion house paints were reported to be acrylic-resin emulsions pigmented with titanium dioxide and extending pigments. The coefficients of expansion of films of emulsion paint of brand D (table 3) were relatively low, about equal to those for films of white lead linseed-oil paint (table 2), and changed little when the films were aged or

weathered. Alkyd emulsion primer, brand D, made films that expanded substantially more than the finish paint of brand D before the films were weathered, but after weathering the film of brand D primer expanded less than any other paint film tested, whether of oil or emulsion type. Nevertheless, the expansion in area of the weathered film of primer D exceeded that of flat-grain surfaces of southern yellow pine. Unweathered films of brand A emulsion paint had fairly high expansion that became still higher as the films aged or were weathered, whereas weathering sharply reduced the expansion of films of brand B emulsion paint.

For films of the emulsion paints, the ratio of coefficients of linear expansion, B/L, fell between 0.8 and 1.2 (except for a single observation of 1.4 for the aged film of emulsion primer D), although all of the emulsion paints presumably contained a substantial proportion of acicular pigments. It is possible that during coalescence of the film the droplets of acrylic resin largely disarrange any orientation of acicular pigments brought about by flow during application.

Thermal Coefficients Above and Below 21° C.

Table 4 reports the coefficients of thermal expansion for the temperature range 21° to 0° C. and for the temperature range 55° to 21° C. Since the coefficients for any one paint film did not differ very greatly in the two temperature ranges, it suffices for the present purpose to report the average coefficients for the 10 linseed-oil paints, for the titanium alkyd-resin paint, for the 2 oil-type primers for emulsion paints, and for the 4 emulsion paints and primer.

The results indicate that the coefficients usually were slightly greater for the higher temperature range than for the lower. The one exception was the average for the 9- to 11-day-old linseed-oil paints for which the average linear coefficient across the grain and the average areal coefficient were somewhat smaller for the higher temperature range.

Residual Changes in Dimensions After a Cycle of Expansion Measurements

When the paint films were cooled from 21° to 0° C., warmed to 55° C., and then restored to 21° C., they rarely resumed their initial dimensions. Usually the final length and width were less and the thickness presumably greater than the initial dimensions. Occasionally the final length and width exceeded the initial dimensions. In table 5 the residual changes in dimensions are reported as parts per million (10^6) instead of percentages in order that both residuals and thermal coefficients may be tabulated in numbers to the same power of 10. It should be remembered, however, that the thermal coefficients must be multiplied by the temperature span to learn the total change in dimension experienced by the film during test. Thus for the 9-day-old film of white lead paint the total expansion in area from 0° to 55° C. (table 2) was $5,445 \times 10^{-6}$ and the residual change in area after the test cycle (table 5) was -490×10^{-6} . For the 10-day-old film of paint T p/nv 0.30, the total expansion in area from 0° to 55° C. was $17,655 \times 10^{-6}$ and the residual change in area was $-2,810 \times 10^{-6}$. In general, the residual change was about 9 to 16 percent of the total expansion between 0° and 55° C.

A residual change in the volume of the films is possible but seems unlikely. If the volume is assumed to have returned precisely to its initial value after a cycle of changes in

temperature, the residual change in area must have been compensated by a residual change in thickness of opposite sign. Such accommodations of linear dimensions are readily attained in films that are reasonably plastic and are indeed essential in coatings if they are to remain intact on substrates that differ from the coatings in their changes in surface area. It appears, therefore, that the free paint films tested usually expanded somewhat less in area but correspondingly more in thickness when the temperature rose from 0° to 55° C. than they contracted when they were subjected to falling temperatures.

The plastic deformation of a paint film during a cycle of temperature changes, which was shown previously (4, 5) to occur also during swelling with moisture and redrying, probably varies in magnitude with the speed with which the change from one condition to the other is brought about. In these experiments the temperature was altered rapidly, well within 15 minutes. With slower changes in temperature, as in Dunn's tests (10), less of the plastic deformation might be expected.

Changes in Weight and Dimensions of Films While Aging

The interval between the first and second tests of the expansion of the unweathered paint films afforded data on the changes in weight and dimensions that occurred from aging for approximately one month under laboratory conditions. Table 6 reports the findings.

All films lost weight and shrank in length, width, and area. The losses came, of course, from evolution of volatile products of low molecular weight formed by disruptive oxidation of the paint vehicles. Linseed-oil paints lost between 11.1 and 32.4 milligrams per cubic centimeter and shrank in area between 11,600 and 34,900 parts per million (1.16 to 3.49 percent). The shrinkage in area was not proportional to the loss in weight, but it is known from previous work (5) that there was also an increase in the density of the films, hence a shrinkage in volume, the extent of which varied with the composition of the paint. For paints TxZ₁₇ p/nv 0.26, and TxZ₁₇ p/nv 0.475, which differed only in proportions of total pigment and oil vehicle, both weight loss and shrinkage were greater for the one with the greater proportion of oil.

The oil-type paints with varnish vehicles, Tx(ar) p/nv 0.30, and oil-type primers B and D, lost only 6.1 to 8.9 milligrams per cubic centimeter but shrank in area 10,100 to 12,400 parts per million (1.01 to 1.24 percent); their shrinkage was nearly as much as that of some of the linseed-oil paints with twice as much weight loss. The weight lost by the emulsion paints, 9.3 to 16.3 milligrams per cubic centimeter, was intermediate between that of the linseed-oil and varnish-vehicle paints, but the shrinkage in area of the emulsion paints was low, only 5,100 to 10,300 parts per million (0.51 to 1.03 percent). It is noteworthy that the emulsion paints, which contained no drying oil and presumably dried entirely by evaporation of solvent without oxidation, nevertheless lost weight steadily during aging, even without exposure to the weather. In other tests not reported here, the loss in weight was still going on after these films had been in the laboratory more than a year. Apparently the acrylic emulsion vehicles, like oil-type vehicles, are subject to disruptive oxidation and loss of volatile products.

Conclusions

1. The thermal expansion of free films of house paints, both the oil type and the newer emulsion type, is much greater than the thermal expansion of the denser and therefore

more expansive softwoods, such as southern yellow pine. Paint films expand in area from nearly twice to six times as much as flat-grain surfaces of southern yellow pine. If differences between wood and paint coatings in their tendencies to move in the plane of their interface were responsible for disruption of the coatings, paints should last longer on southern yellow pine than on western redcedar and longer on flat-grain than on edge-grain surfaces. More plausible theories for the effect of wood properties on paint durability have been offered elsewhere (11, 13).

2. Within the range of temperature of practical significance, the thermal expansion of house paint coatings is less than their moisture swelling.

3. There are a number of parallels between thermal movement and moisture movement of paint films. Among linseed-oil paints at least, the movement with change in either temperature or moisture content is much greater with some kinds of pigments than with others. For paints with the same kind of pigments and vehicle, the movement is less the higher the pigment volume, that is, the greater the content of total pigment. The movement is less for the acrylic emulsion paints tested than for most of the linseed-oil paints except pure white lead paint. Oil paints containing acicular pigments, when applied by brush or doctor blade, form anisotropic coatings because of orientation of the acicular pigments during the last flow of the liquid paint. Such paints possess grain and move more at right angles to the last direction of flow than in the parallel direction. Such anisotropy may be less marked in films of emulsion paints than in films of oil paints, possibly because coalescence of the droplets of emulsion during hardening may disarrange any orientation of acicular pigments during application.

4. The coefficients of thermal expansion of paint films tend to be slightly greater for the range in temperature between 21° and 55° C. than for the range between 21° and 0° C. The differences, however, are not great enough to become important.

5. When free paint films are subjected to a cycle of changes in temperature (or of moisture content) and are brought back to the initial temperature (or moisture content), they seldom return to the initial dimensions. The residual change in area is of the order of 9 to 16 percent of the thermal movement from a 55° C. change in temperature. It is presumed that the films become plastically deformed. The alteration in surface area may be compensated by an opposite alteration in film thickness.

6. Paint films lose weight and shrink in dimensions as they become older even when they are kept under the mild conditions of indoor exposure. These losses are not confined to oil paints that dry by oxidation but occur also, only slightly less markedly, in acrylic emulsion paints that dry entirely by evaporation of solvent. The losses are due to disruptive oxidation of the organic vehicle with escape of volatile products of low molecular weight. In addition there is further shrinkage from a gradual increase in density of the films.

7. Difference in movement between wood and paint coatings undoubtedly puts stress on the coatings. It is not a case, however, of coatings being unable to follow excessive movement of the wood but rather of coatings trying to run far ahead of the wood. Largely by reason of its cellular structure, wood moves much less than might be supposed from the nature of cellulose and lignin. Even so, stresses in the coating resulting from differences between paint and wood movement are small in comparison with the stresses that gradually accumulate in the coating from its own contraction from disruptive oxidation, its increase in density; and its own thermal and moisture movement independently of its attachment to the wood. Paint coatings are not "murdered" by wood. On the contrary, they "commit suicide."

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Table 1.--Coefficients of thermal expansion of some woods that are often painted

Kind of wood	Specific gravity, ovendry weight and volume	Coefficient of expansion ¹		
		In linear dimension	In area of surface	In volume
Western redcedar	0.33	3.6	26.7	18.5
Douglas-fir	.51	4.5	41.3	28.6
Southern yellow pine	.61	4.5	49.5	34.2
Summerwood bands	.95	4.5	249.5	53.1
Springwood bands	.29	4.5	249.5	16.2

¹Per °C. x 10⁶.

²Because summerwood and springwood are bound together in the tangential direction, they must move very nearly in unison in that direction to an extent nearly equal to the overall movement across the grain of a flat-grain surface.

Table 2.--Coefficients of thermal expansion of free films of
linseed-oil paints in the range from 0° to 55° C.
(32° to 132° F.)

Kind of paint	Age	Time under	Thick-	Coefficient of expansion ¹			Ratio $\Delta B/\Delta L$
	of film:	artificial: weathering:	ness of film	Linear	In	area	
				With the	Across the	ΔQ	
				grain,	grain,		
				ΔL	ΔB		
	<u>Days</u>	<u>Days</u>	<u>Mils</u>				
White lead	: 9 :	0	: 3.7 :	48	: 51	: 99	: 1.1
L p/nv 0.30	: 37 :	0	: :	44	: 40	: 84	: .9
	: 37 :	15	: 3.0 :	46	: 46	: 92	: 1.0
Zinc oxide	: 10 :	0	: 3.6 :	85	: 148	: 233	: 1.7
Z p/nv 0.30	: 38 :	0	: :	58	: 129	: 187	: 2.2
	: 38 :	15	: 3.0 :	38	: 104	: 142	: 2.7
Titanium dioxide	: 10 :	0	: 3.5 :	175	: 146	: 321	: .8
T p/nv 0.30	: 39 :	0	: :	154	: 140	: 294	: .9
	: 38 :	15	: 2.7 :	95	: 90	: 185	: .9
Antimony oxide	: 10 :	0	: 3.7 :	180	: 160	: 340	: .9
A p/nv 0.30	: 39 :	0	: :	159	: 153	: 312	: 1.0
	: 39 :	15	: 3.0 :	89	: 103	: 192	: 1.2
Magnesium silicate	: 11 :	0	: 3.7 :	69	: 113	: 182	: 1.6
X p/nv 0.30	: 40 :	0	: :	75	: 107	: 182	: 1.4
	: 40 :	15	: 2.6 :	48	: 76	: 124	: 1.6
Titanium-lead	: 10 :	0	: 3.9 :	96	: 142	: 146	: 1.5
TxL ₄₀ p/nv 0.30	: 43 :	0	: :	93	: 133	: 226	: 1.4
	: 43 :	15	: 3.3 :	66	: 92	: 158	: 1.4
Titanium-zinc	: 10 :	0	: 4.0 :	89	: 141	: 230	: 1.6
TxZ ₂₀ p/nv 0.30	: 43 :	0	: :	67	: 125	: 192	: 1.9
	: 42 :	15	: 3.3 :	68	: 110	: 178	: 1.6
Titanium-zinc	: 11 :	0	: 3.7 :	115	: 134	: 249	: 1.2
TxZ ₁₇ p/nv 0.26	: 44 :	0	: :	100	: 130	: 230	: 1.3
	: 44 :	15	: 3.6 :	91	: 106	: 197	: 1.2
Titanium-zinc	: 11 :	0	: 3.0 :	75	: 88	: 163	: 1.2
TxZ ₁₇ p/nv 0.475	: 45 :	0	: :	70	: 89	: 159	: 1.3
	: 45 :	15	: 2.9 :	54	: 69	: 123	: 1.3
Titanium-lead-zinc	: 10 :	0	: 3.9 :	71	: 117	: 188	: 1.6
TxL ₂₀ Z ₂₀ p/nv 0.30	: 42 :	0	: :	75	: 129	: 204	: 1.7
	: 39 :	15	: 1.7 :	71	: 104	: 175	: 1.5

¹Per °C. x 10⁶.

Table 3.--Coefficients of thermal expansion of free films of alkyd-resin paint, primers for emulsion paints, and acrylic emulsion house paints in the range from 0° to 55° C. (32° to 132° F.)

Kind of paint	Age of film	Time under artificial weathering	Thickness of film	Coefficient of expansion ¹		Ratio $\Delta B/\Delta L$	
				Linear	In area		
				With the grain, ΔL	Across the grain, ΔB	ΔQ	
	Days	Days	Mils				
Titanium alkyd-resin paint	11	0	2.5	70	91	161	1.3
Tx(ar) p/nv 0.30	44	0	.....	71	88	159	1.2
	43	15	2.2	40	41	81	1.0
Oil-type primer for use under emulsion paint of Brand B	10	0	3.4	138	147	285	1.1
	47	0	.....	120	154	274	1.3
	47	15	3.0	57	51	108	.9
Oil-type primer for use under emulsion paint of Brand D	10	0	4.2	106	152	258	1.4
	48	0	.....	100	130	230	1.3
	48	15	3.4	66	75	141	1.1
Emulsion primer for use under emulsion paint of Brand D	10	0	3.0	59	70	129	1.2
	48	0	.....	61	85	146	1.4
	48	15	2.4	32	32	64	1.0
Acrylic emulsion house paint of Brand A	9	0	2.3	67	75	142	1.1
	43	0	.....	86	104	190	1.2
	43	15	2.1	83	95	178	1.1
Acrylic emulsion house paint of Brand B	9	0	2.9	58	61	119	1.1
	44	0	.....	58	69	127	1.2
	44	15	2.3	42	48	90	1.1
Acrylic emulsion house paint of Brand D	10	0	2.3	46	37	83	.8
	44	0	.....	40	45	85	1.1
	44	15	1.8	43	50	93	1.2

¹Per °C. x 10⁶.

Table 4.--Comparison of thermal coefficients of expansion in the range from 21° to 0° C. (70° to 32° F.) with those in the range from 55° to 21° C. (132° to 70° F.)

Kind of paint	Coefficient of expansion ¹			In area, ΔQ
	Linear	Across the grain, ΔB		
	With the grain, ΔL	Across the grain, ΔB		
1. Linseed oil paints (averages for 10 paints)				
Films aged 9 to 11 days	107	108	140	247
Films aged 37 to 45 days	88	94	119	207
Weathered films	68	79	96	163
2. Titanium alkyd-resin paint				
Film aged 11 days	78	85	109	187
Film aged 44 days	65	73	76	141
Weathered film	61	60	67	128
3. Oil-type primers for emulsion paints (averages for 2 primers)				
Films aged 10 days	127	129	151	278
Films aged 47 or 48 days	93	107	116	209
Weathered films	71	86	82	153
4. Emulsion house paints (averages for 4 paints)				
Films aged 9 or 10 days	48	73	66	114
Films aged 43 to 48 days	60	66	78	138
Weathered films	52	61	60	112

¹Per °C. x 10⁶.

Table 5.--Differences in dimensions of films at 21° C.
(70° F.) before and after submission to a
cycle of changes in temperature

Kind of paint	Difference in dimension (gained (+) or lost (-))		
	With the grain: ΔL	Across the grain: ΔB	Area ΔQ
	<u>Parts per million</u>	<u>Parts per million</u>	<u>Parts per million</u>
L p/nv 0.30			
Film aged 9 days	-400	-90	-490
Film aged 37 days	-190	-210	-400
Weathered film	-50	-20	-70
Z p/nv 0.30			
Film aged 10 days	-350	-930	-1,280
Film aged 38 days	-200	-520	-720
Weathered film	-220	-370	-590
T p/nv 0.30			
Film aged 10 days	-1,570	-1,240	-2,810
Film aged 39 days	-590	-380	-970
Weathered film	-1,030	-950	-1,980
TxL40 p/nv 0.30			
Film aged 10 days	-140	-210	-350
Film aged 43 days	-150	-350	-500
Weathered film	-520	-900	-1,420
TxL20Z20 p/nv 0.30			
Film aged 10 days	-300	-260	-560
Film aged 42 days	+280	-100	+180
Weathered film	-260	-660	-920
Tx(ar) p/nv 0.30			
Film aged 11 days	-360	-480	-840
Film aged 44 days	+80	+350	+430
Weathered film	-990	-1,450	-2,440
Oil primer, Brand B			
Film aged 10 days	+160	+100	+260
Film aged 47 days	+360	+330	+690
Weathered film	-1,460	-1,910	-3,370
Emulsion paint, Brand A			
Film aged 9 days	-1,190	-1,380	-2,570
Film aged 43 days	-130	-90	-220
Weathered film	-230	-320	-550
Emulsion paint, Brand B			
Film aged 9 days	+540	-350	+190
Film aged 44 days	-10	-130	-140
Weathered film	-350	-520	-870
Emulsion paint, Brand D			
Film aged 10 days	-500	-1,100	-1,600
Film aged 44 days	-280	-630	-910
Weathered film	-300	-440	-740

Table 6.--Reduction in weight and dimensions of films while aging in the laboratory for the time interval indicated

Kind of paint	Time	Change in--			
	Interval	Weight	Dimension		
From: To	Weight	Dimension	Area		
age : age	:With the	: Across	: ΔQ		
:	: grain, ΔL :	the grain:	:		
:	:	:	: ΔB		
:	:	:	:		
Days: Days:	Mg/cc.:	Parts per:	Parts per:		
:	:	million :	million :		
L p/nv 0.30	9 : 37	-13.0	-7,200	-7,100	-14,200
Z p/nv 0.30	10 : 38	-11.3	-8,100	-11,000	-18,900
T p/nv 0.30	10 : 39	-25.8	-19,000	-16,200	-34,900
A p/nv 0.30	10 : 39	-32.4	-16,100	-12,400	-28,300
X p/nv 0.30	11 : 40	-20.7	-9,700	-17,400	-26,900
TxL40 p/nv 0.30	10 : 43	-16.1	-8,300	-14,300	-22,500
TxZ20 p/nv 0.30	10 : 43	-15.3	-7,700	-14,000	-21,600
TxZ17 p/nv 0.26	11 : 44	-15.0	-6,000	-6,600	-12,600
TxZ17 p/nv 0.475	11 : 45	-11.1	-5,200	-6,400	-11,600
TxL20Z20 p/nv 0.30	10 : 42	-17.6	-5,500	-10,600	-16,000
Titanium alkyd-resin paint,	:	:	:	:	:
Tx(ar) p/nv 0.30	11 : 44	-8.9	-4,600	-5,500	-10,100
Oil-type primer, Brand B	10 : 47	-9.5	-5,200	-5,200	-10,200
Oil-type primer, Brand D	10 : 48	-6.1	-6,300	-6,100	-12,400
Emulsion primer, Brand D	10 : 48	-16.3	-3,100	-4,300	-7,100
Emulsion paint, Brand A	9 : 43	-14.6	-5,200	-5,100	-10,300
Emulsion paint, Brand B	9 : 44	-9.3	-2,100	-4,000	-6,100
Emulsion paint, Brand D	10 : 44	-14.5	-2,100	-3,000	-5,100