RESEARCH REPORTS

INFRA-RED TRANSMISSON OF WOOD

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Abstract

The intensity of infra-red radiation which passes through the wood was measured, and the following results were obtained.

(1) Absorption coefficients of various kinds of wood are distributed between 0.1 mm^{-1} and 13.0 mm^{-1}, except some special specimens.

(2) Transparency of wood increases with the moisture content and the curve which shows this relation has a marked knick at certain point.

(3) No correlation is observed between the absorption coefficient and the density, the space constant or the hardness of the wood.

1. Introduction

It is often observed that the photographic plate, especially the infra-red sensitive one, in the wooden draw slide is fogged considerably. This is probably because the wood is more or less transparent for the infra-red rays. Hence, the absorption coefficients of more than one hundred kinds of wood were measured by the photographic method to find the origine of this fog.

2. Experimental Procedure

Wooden block in the state of oven dry was cut into the shape of a wedge, 75 mm long, 20 mm wide and with the maximum thickness of 7 mm. This wegde-like specimen placed on a Fuji infra-red 820 dry plate (maximum sensitivity at 820 $m\mu$) with a spacer of aluminum foil between them. Aluminum foil has five rectangular apertures 70×7 mm^2 to expose the radiation to fall on the plate. Thus five specimens could be tested on one plate at the same time.

The light source was an ordinary 100 watts incandescent lamp. The light from this source was focused on a pin-hole 2 mm in diameter, made parallel with a convex lens, and then sent on the specimen. The distance between the source and the specimen was one meter. The intensity of illumination on the specimen was about 1 lux. This arrangement is shown in Fig. 1.

The time of exposure was one minute. The plate was developped with the Fuji FD-104 developer. The time of development was 5 minutes and the temperature of the developer was kept constant at $20 \pm 0.5°$ C by means of a constant temperature bath.

The density of the plate thus obtained was measured with a microphotometer, The thickness of the specimen was determined with a micrometer as accurate as possible.

In order to get the relation between the moisture content and the transmission, the specimen was first dried completely, and then the air absorbed in it was driven out in a vacuum vessel. After this the specimen was again made sufficiently wet by introducing distilled water into the vessel. The excess water on its surface was wiped off with a sheet of filter paper. Thus the experiment was started from the second stage of falling rate of drying, and the transmission was determined at various moisture content.

The Rockwell hardness testing machine was used to measure the hardness of the specimen. The steel bar, one end of which was shaped a semi-sphere of diameter 1 cm, was pressed on the specimen with the weight of 30 kg, and the diameter of the round cavity thus formed on the surface was taken as the measure of hardness for the specimen. The value of hardness in the table was obtained by averaging the results of three experiments.

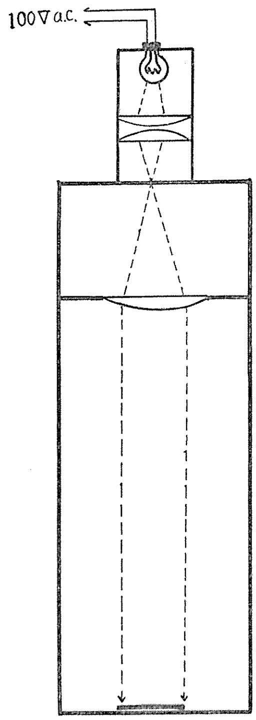

FIG. 1. Schema of optical system.

3. Experimental Results

Fig. 2 shows the photographic plates exposed to the radiation which has passed through the wedge-shaped specimens of woods. If the trasmission factor of the exposed plate is plotted against the corresponding thickness of the specimen, the curves as shown in Fig. 3 are obtained.

Let I_1 and I_2 are the intensities of radiation that have passed the distances d_1 and d_2 of the specimen respectively. Then,

$$I_1 = Ie^{-\alpha d_1}, \quad I_2 = Ie^{-\alpha d_2} \qquad (I = \text{Intencity of the incident radiation})$$

and,

$$\log I_1 - \log I_2 = \alpha(d_2 - d_1)$$

where α is the absorption coefficient.

If the densities of the photographic plate corresponding to I_1 and I_2 are D_1 and D_2 respectively,

$$D_1 - D_2 = \frac{1}{k}\alpha(d_2 - d_1)$$

$$\frac{1}{k} = \text{constant}$$

provided that D_1 and D_2 are on the straight line portion of the characteristic curve of the photographic plate. Using the ralation

$$D = \log_{10}\frac{1}{T} \qquad (T = \text{transmission of the plate})$$

this can be written down as

$$\log_{10} T_2 - \log_{10} T_1 = \frac{1}{k}\alpha(d_2 - d_1)$$

Hence, the absorption coefficient α is given by

$$\alpha = k\frac{\log_{10} T_2 - \log_{10} T_1}{d_2 - d_1}$$

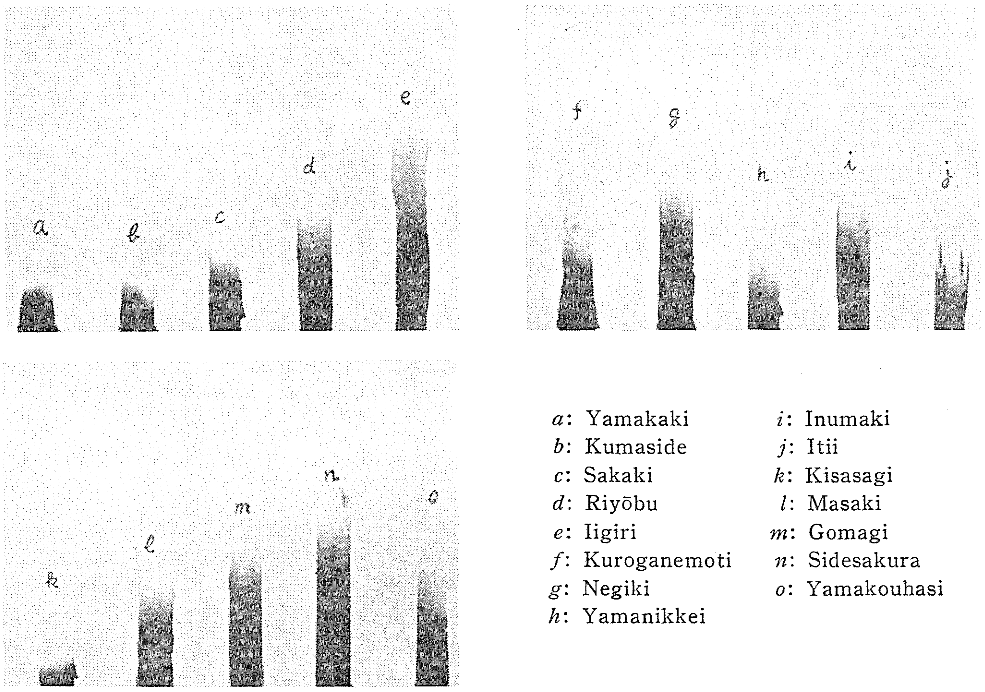

FIG. 2. Exposed images by wedge-like specimens (Fuji infra-red plate 820).

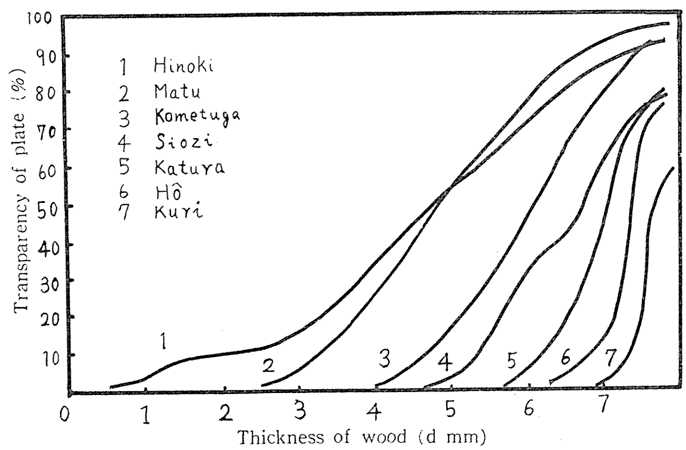

FIG. 3. Microphotometric curves of exposed images.

As is easily seen from this formula, the absorption coefficient of the specimen is proportional to the gradient of the $\log_{10} T$—d curve (Fig. 4).

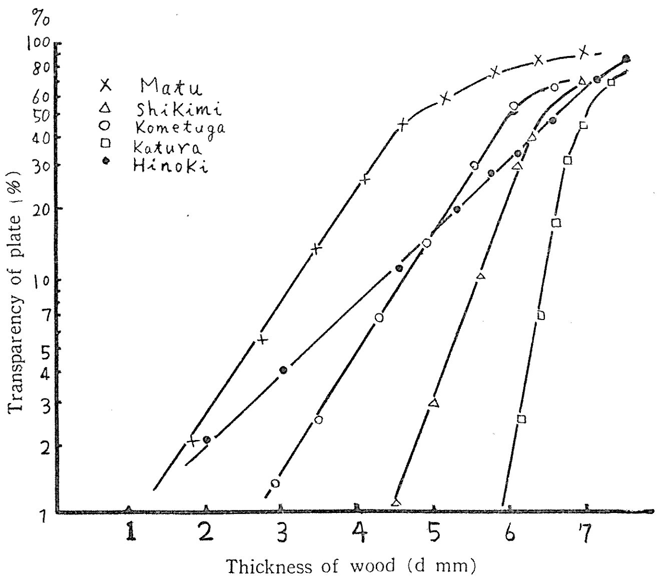

FIG. 4. Variation of plate transparency v.s. sample thickness.

The constant k can be determined if the same experiment as described in section 2 is carried out by placing specific specimen (*Pinus thunbergii*) and the neutral optical wedge on the same photographic plate, because in this case α and $(\log_{10} T_2 - \log_{10} T_1)/(d_2 - d_1)$ can be determined independently. Once k is determined, the absorption coefficient of other specimen can be obtained by comparing the gradient of the $\log_{10} T$—d curve. This procedure seems to be awkward to get the absorption coefficient itself, but it has the advantage that the $\log_{10} T$—d curve shows clearly how the radiation penetrates into the specimen.

In the present experiment using the Fuji infra-red 820 plate, k is equal to 5.5_5.

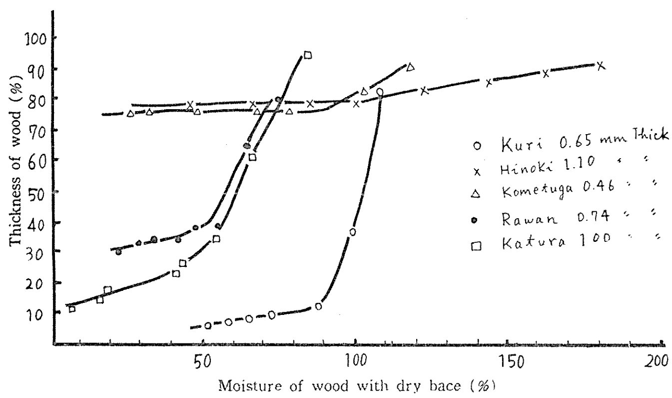

FIG. 5. Variation of transparency v.s. sample moisture.

TABLE I

Japanese name	Scientific name	$\alpha(mm^{-1})$	R.H.N.	s.g.	c.
Akagasi	*Quercus acuta*	Opaque	79.0	0.97	0.38
Akamegasiwa	*Mallotus japonicus*	1.44	32.2	0.59	0.63
Asebi	*Pieris japonica*	1.00	39.9	0.70	0.55
Aburagiri	*Aleurites cordata*	2.18	29.3	0.46	0.65
Abemaki	*Quercus variabilis*	4.60	61.7	0.96	0.39
Baribarinoki	*Aotinodaphne acuminata*	8.76	34.5	0.68	0.56
Enoki	*Celtis sinensis*	9.24	52.4	0.77	0.50
Gamazumi	*Viburnus dilatatum*	1.17	66.0	0.99	0.36
Gomagi	*Viburnum sieboldii*	1.66	52.9	0.82	0.47
Gonzui	*Euscaphis japonica*	3.66	51.1	0.78	0.50
Hamakusagi	*Premna microphylla*	5.80	57.1	0.91	0.41
Hannoki	*Alunse japonica*	1.41	31.2	0.60	0.61
Hiiragi	*Osmanthus ilicifolius*	6.66	62.7	0.95	0.39
Hisakaki	*Eurya japonica*	3.02	53.8	0.80	0.48
Hinoki	*Chamaecyparis obtusa*	1.43	23.7	0.38	0.75
Himesyara	*Stewartia monadelpha*	0.82	56.3	0.89	0.42
Hô	*Vitex rotundifolia*	9.66	42.5	0.49	0.69
Horutonoki	*Elaeocaerpus decipieus*	6.32	30.0	0.52	0.66
Iigiri	*Idesia polycarpa*	0.14	24.3	0.48	0.69
Isonoki	*Frangula crenata*	6.22	42.8	0.74	0.53
Isunoki	*Distylium racemosum*	0.43	78.5	1.01	0.35
Itii	*Taxus cuspidata*	2.65	65.5	0.89	0.43
Inukaya	*Cephalotaxus drupacea*	1.18	50.1	0.66	0.58
Inusansô	*Fagara schinifolia*	4.40	57.0	0.89	0.43
Inumaki	*Podocarpus macrophylla*	1.95	34.8	0.59	0.63
Kakuremino	*Gilibertia trifida*	2.12	32.1	0.60	0.61
Katura	*Cercidiphyllum japonicum*	10.1	41.0	0.47	0.70
Kanakuginoki	*Benzoin erythrocarpum*	Opaque	41.0	0.78	0.50
Kaede	*Acer palmatum*	6.18	52.0	0.84	0.46
Karasusansô	*Fagara ailauthides*	3.40	41.8	0.56	0.64
Kankonoki	*Glochidion obovatum*	3.70	48.4	0.82	0.48
Kanzaburônoki	*Symplocos theophrastaefolia*	2.65	36.8	0.55	0.65
Kisasagi	*Catalpa ovata*	4.65	27.5	0.56	0.64
Kibusi	*Stachyurus praecox*	3.84	43.6	0.68	0.56
Kusagi	*Clerodendron trichotomum*	1.23	36.0	0.68	0.56
Kusunoki	*Cinnamomum camohora*	5.55	45.0	0.72	0.54
Kunugi	*Quercus acutissima*	2.36	42.0	0.67	0.57
Kumaside	*Carpinus carpinoides*	4.98	45.2	0.85	0.46
Kumanomizuki	*Cornus brachypoda*	1.26	42.0	0.96	0.38
Kurinoki	*Castanea pubinervis*	6.16	74.6	0.52	0.66
Kuroganemoti	*Ilex rotunda*	4.94	47.5	0.66	0.58
Kurobai	*Symplocos prunifolia*	0.84	34.8	0.68	0.56
Kuromozyu	*Benzoin umbellatum*	1.86	51.8	0.69	0.56
Keyaki	*Zelkova serrata*	4.10	47.9	0.84	0.46
Konara	*Quercus serrata*	5.41	57.5	0.88	0.43
Kobanotoneriko	*Fraxinus longicuspis*	3.66	60.3	0.73	0.54
Kometuga	*Tsuga diversifolia*	2.84	27.0	0.52	0.66
Matu	*Pinus thunbergii*	2.71	46.1	0.55	0.65
Masaki	*Euonymus japonica*	4.11	50.9	0.78	0.50
Mayumi	*Euonymus sievoldiana*	1.25	18.5	0.54	0.66
Mimizubai	*Symplocoo glauca*	2.06	27.0	0.58	0.63
Mukunoki	*Aphananthe aspera*	5.84	68.2	0.79	0.49
Murasakisikibu	*Callicarpa japonica*	1.94	60.8	0.99	0.37
Meurikaede	*Acer crataegifolium*	0.29	39.2	0.65	0.58
Motinoki	*Ilex integra*	3.26	61.3	0.96	0.39
Momi	*Abies firma*	1.31	45.8	0.76	0.51
Nara	*Quercus serrata*	0.79	41.0	0.56	0.64
Nigaki	*Picrasma ailanthoides*	1.06	54.3	0.74	0.53
Nurude	*Rhus javanica*	5.34	35.3	0.57	0.63
Nesiki	*Piris elliptica*	2.32	54.4	0.99	0.46

TABLE I. (*Continued*)

Japanese name	Scientific name	α(mm⁻¹)	R.H.N.	s.g.	c.
Nezumimoti	*Liqustrum japonicum*	0.44	77.5	1.19	0.24
Nemunoki	*Albizzia julibrissin*	7.59	44.5	0.66	0.58
Noriusugi	*Hydrangea paniculata*	0.69	47.9	0.82	0.47
Ogatama	*Michelia compressa*	1.12	40.7	0.63	0.60
Ryobu	*Clethra barbinervis*	1.26	53.4	0.82	0.47
Rinboku	*Prunus spinulosa*	3.01	54.0	0.93	0.40
Sakaki	*Cleyera ochnacea*	4.74	46.3	0.74	0.53
Sansô	*Xanthoxylum piperitum*	2.38	43.2	0.73	0.53
Sii	*Shiia cuspidata*	6.41	33.8	0.52	0.74
Siozi	*Fraxinus verecunda*	4.06	22.2	0.39	0.74
Sikimi	*Illicium religiosum*	4.92	58.1	0.72	0.54
Sidesakura	*Amelauchier asiatica*	2.08	78.1	1.09	0.30
Sinanokaki	*Diospyros latus*	11.7	58.0	0.69	0.56
Siraki	*Sapium japonicium*	4.46	54.8	0.80	0.48
Sirodamo	*Litsea glauca*	5.80	35.7	0.72	0.54
Sugi	*Cryptomeria japonica*	4.11	26.5	0.37	0.76
Sennoki	*Kalopanax ricinifolius*	5.41	—	0.49	0.68
Soyogo	*Ilex pedunculosa*	0.84	54.3	0.94	0.40
Taimintatibana	*Rapanaea neriifolia*	2.28	59.4	0.91	0.42
Takanotume	*Kalopanax innovans*	7.83	43.9	0.63	0.59
Tabunoki	*Machilus thunlergii*	5.13	37.8	0.56	0.64
Tamamizuki	*Ilex micrococca*	0.22	27.2	0.47	0.69
Taranoki	*Aralia elata*	3.77	30.2	0.49	0.68
Tubaki	*Camellia japonica*	1.88	58.0	0.87	0.45
Tokiwagaki	*Diospyros nipponica*	9.36	58.8	0.80	0.49
Tobera	*Pittosprum tobira*	5.75	54.9	0.88	0.43
Usigorosi	*Rhamnus clahurica*	4.14	57.0	1.03	0.34
Utugi	*Deutzia crenata*	2.82	56.4	0.85	0.45
Ubamegasi	*Quercus phillyraeoides*	Opaque	76.8	0.98	0.37
Umemodoki	*Ilex serrata*	2.46	44.2	0.83	0.47
Urusi	*Rhus verniciflua*	6.67	34.2	0.71	0.55
Yabunikkei	*Cinnamomum japonicum*	2.21	46.5	0.62	0.60
Yamakaki	*Diospyros kaki*	7.34	55.4	0.85	0.46
Yamaguruma	*Trochodendron aralioides*	7.60	53.8	0.76	0.51
Yamakoubasi	*Benzoin glaucum*	1.93	76.0	1.08	0.31
Yamasakura	*Prnus donarium*	1.26	42.8	0.75	0.52
Yamanasi	*Malus tschnoskii*	2.53	54.8	0.93	0.40
Yamabiwa	*Meliosma rigida*	1.78	45.2	0.68	0.57
Yamabousi	*Corunus kousa*	0.08	63.6	1.00	0.36
Yamamomo	*Myrica rubra*	3.64	47.8	0.76	0.51
Yuzuriha	*Daphuiphyllum macropodum*	4.13	46.9	0.79	0.50

α; Absorption coefficient. R.H.N.; Rockwell hardness number. s.g.; Specific gravity. c.; Space constant.

Scientific name are introduced from Illustrated Flora of Nippon by Tomitarô Makino (1940).

The absorption coefficients of various woods thus obtained are given in Table I.

The transmissions of the wood with the thickness of 1 mm lie between 0 and 95%, when they are in oven dry. The oak (*Fagaceae*) is so opaque to light that the measurement of the absorption coefficient is impossible. The needleleaf trees, such as the pine-tree (*Pinus thunbergii*), the Japanese cedar (*Cyptomeria japonica*), Kometuga (*Tsuga diversifolia*) and the Japan cypress (*Chamaecyparis obtusa*) have comparatively high transmission, while the broad-leaves trees, such as the chestnut-tree (*Castanea pubinervis*), the hô (*Vitex rotundifolia*) and the Japanese Judas-tree (*Cercidiphylum japonicum*) have comparatively low transmission.

With increase of moisture content the transmission of wood also increases. At the saturated moisture content, almost all the specimen with the thickness of

1 mm exhibit the transmission greater than 80%. Although the transmission decreases rapidly as the specimen is dried, the rate of decrease changes abruptly at a certain point and the curve becomes nearly horizontal (Fig. 5).

The specific gravity of wood which is a measure of compactness seems to be in close relation to the transmission. Hence, this relation is shown in Fig. 6. On the other hand, it is a general opinion that the specific gravity of the substance constituting the cell membrane of wood is almost the same for any species and is equal to 1.56.[1] If m is the fraction of the volume which the real substance in wood occupies, c is the space constant and ρ is the apparent density,

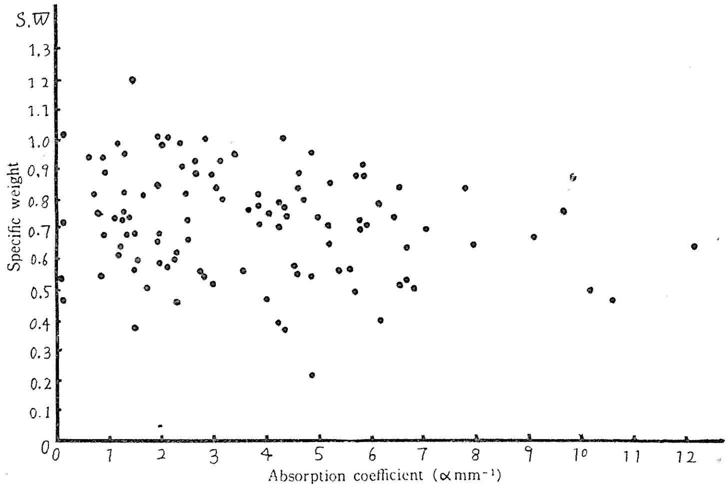

FIG. 6. Distribution between specific weight and absorption coefficient.

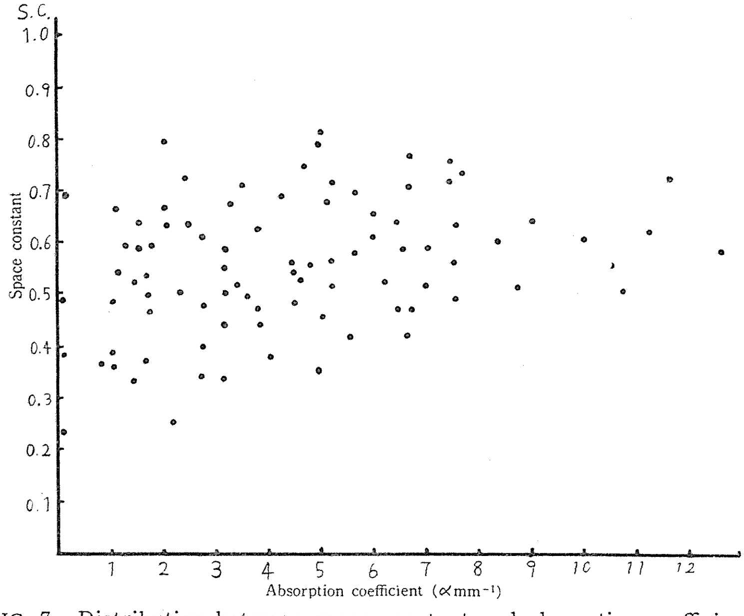

FIG. 7. Distribution between space constant and absorption coefficient.

$$c = 1 - m = 1 - \frac{\rho}{1.56} = 1 - 0.641\,\rho$$

The relation of this space constant to the absorption coefficient is shown in Fig. 7.

Fig. 6 and Fig. 7 indicate that neither the specific gravity nor the space constant is the important factor to determine the absorption coefficient of wood.

It is also said that the harder the wood is, the more opaque it is to light,[2] but, according to the author's experiment, no correlation between the hardness and the absorption coefficient is observed as shown in Fig. 8.

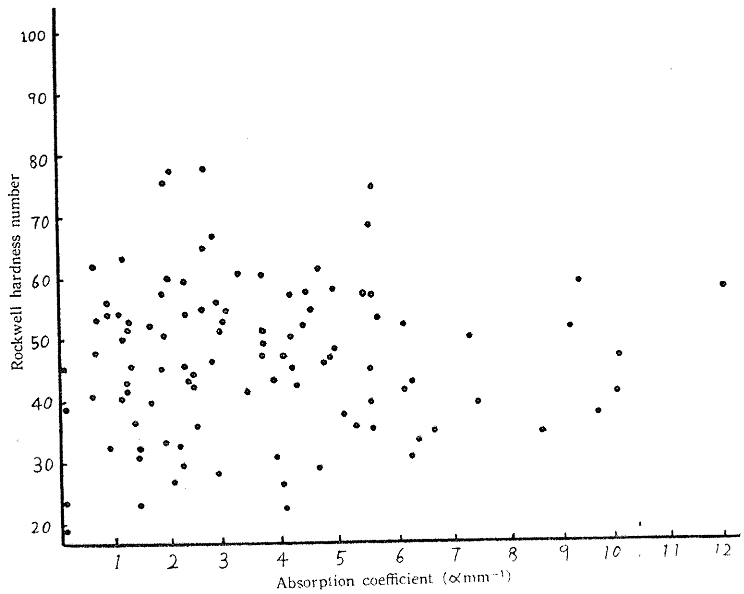

FIG. 8. Distribution between hardness and absorption coefficient.

4. Summary

In the measurement of the physical constant of wood, it is almost hopeless to obtain the same results even with the same specimen, much less with others of the same species. The foregoing results may, therefore, contain a fairly large errors, but the general tendencies are correct.

Although it is very difficult to give a definite analysis for the mechanism of the transmission of light through wood, the scattering seems to play an important rôle in this phenomenon. Thus, the light which penetrates into the wood is scattered repeatedly among the cell membranes, some fraction of it coming again finally out of the wood and the rest being absorbed.

At any rate, as the wood are much more transparent to radiation (especially to the infra-red radiation) than first expected, the inside of the draw slide carrying photographic plates must be carefully coated with some paint completely opaque to light except when the draw slide is made of thick plates of oak.

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2) J. Lecomte: Le Rayonnement Infra-rouge, p. 117, 1948.