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Fire Retardancy & Charring Rates in Hardwood

We are often asked about the Fire Retardancy of Hardwood, particularly in regards to vandalism and the general life span of the timber, as it is natural to assume that all timber burns and deteriorates easily, when this is not the case.

In this document is a reproduction of the content of a TRADA published report "The Charring Rates of Certain Hardwoods". (A PDF of the original report is available, but it has been reformatted here for your ease)

The report confirms that the denser the Hardwood the better the charring rates. Less dense Hardwoods and Softwoods will char far more than heavier denser Hardwoods.

Woodscape have been manufacturing Street Furniture and timber components for over 40 years using some of the most dense and durable timbers commercially available.

Greenheart and Balau Hardwoods, both with a density in excess of 900Kg/m2 have been our principle timbers for much of this time. With the increasing demand for FSC Hardwoods we have been able to source certified alternatives which are about as dense, namely Cumaru and Iroko.

Based on the findings of the report it would suggest that these newer FSC alternatives with a high density offer very good resistance to charring. Additionally, very dense timbers require the heat intensity of a blow torch to maintain combustion of the wood gases and unless these components are regularly stoked they will cease to burn.

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The Charring Rate of certain Hardwoods

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The use of the words 'timber' or 'wood' in all TRADA publications covers softwoods, hardwoods, plywood, blockboard and particle-boards, as may be appropriate in the context.

Summary

The rate of charring of 50 mm thick blocks of various hardwoods during 40 min exposure to standard time-temperature conditions was determined.

A general, inverse relationship between density and charring rate was found. The values for teak, jarrah and greenheart were less than 67% of the 0.64 mm/min established for softwoods in general. Other dense hardwoods also showed values low enough to justify the use of new factors in fire resistance calculations.

Appreciation

The predictability of the rate of charring of timber is a major attribute. It enables the fire resistance of structural timbers to be computed accurately. A value of 0.64 mm/min was established many years ago for softwoods and has been taken to apply to all timbers for purpose of calculation. This research shows that certain hardwoods show lower rates of charring than the accepted figure. These values are sufficiently different to justify the use of modified charring rates for these species and allow the use of lighter sections of hardwood to be used for a fire resistance equivalent to that of thicker sections of softwood. This would tie in with the better structural properties of many species of hardwood. It is anticipated that these results will be incorporated into an appendix of CP 112 dealing with structural design in timber to withstand fire.

Introduction

In calculating the fire resistance of structural timbers, a steady rate of charring of 0.64 mm/min has been used in the absence of more detailed information on this property of various timber species. This average rate was established by the Joint Fire Research Organisation on tests on softwood timber floors (Lawson, Webster and Ashton, 1951) and has become widely accepted on the basis of this evidence and observations on the charring of timbers in other fire tests. It is a figure which relates only to softwoods and it was felt that hardwoods, with their wide ranging physical/mechanical properties, might give a different value. The denser timbers used for structural purposes could gain advantage in fire resisting design if their rate of charring proved lower than this average figure for less dense timbers.

Certain evidence exists which suggests that this might be the case. Bryan and Doman (1940) tested panels of various timbers for their resistance to penetration by fire. Results on selected species were as follows:

Species	Time
Greenheart	650 sec
Teak	650 sec
Iroko	450 – 500 sec
Jarrah	400 – 450 sec
Opepe	350 – 400 sec
European Oak	350 – 400 sec
Mahogany	250 – 300 sec
Spruce	250 – 300 sec

The test conditions were not particularly representative of those in an actual fire but significant differences in the behaviour of different species were shown.

In tests on the time for small section beams to burn through, Barnes (1940) obtained the following results:

Species	Time
Jarrah	16.5 min
Teak	12.5 min
European Oak	9.2 – 11.0 min

The superiority of teak is not so apparent in these tests but the results of the other two species agree with those of Bryan and Doman in spite of the difference in method of test.

Webster and Ashton (1951) concluded that there was no practical difference between hardwoods and softwood when tested for burn-through in plank form in front of a furnace. The species tested were gurjun, teak, spruce and European redwood in the form of planks of the following thicknesses, 12.7, 25, 38 and 51mm. The joints between the planks were sealed with metal strips and asbestos paper but in spite of these precautions were sometimes the place where flames penetrated. The following values of charring rate in mm/min are taken from their publication.

Thickness, mm	gurjun	spruce	teak	E. redwood
12.7	0.77	0.79	0.60	0.94
25	0.77	0.68	0.63	0.69
38	0.79	0.77	0.71	0.81
51	0.75	0.73	0.55	0.78

It will be seen from these results that teak is slightly superior at all thicknesses and considerably so at the greatest thickness. The other species were very similar in their charring rate.

Other work carried out at the Fire Research Station has suggested that longitudinal permeability (influencing the rate of escape of steam and hot gases) may be of significance in determining the charring rate (JFRO 1963). In the practical situation where the proportion of end grain is very small, this effect is probably less important than found in these tests.

Other results, largely form work carried out at the Forest Products Research Laboratory, Madison, USA, confirm the importance of density as a factor influencing the rate of charring but do not relate to species of hardwoods currently used in the UK. Consequently it was decided to conduct preliminary experiments to determine whether the rate of charring of structural hardwoods was sufficiently different form the average value to justify a different rate being used in calculations. When it became apparent from the preliminary tests that there were useful differences, further tests were carried out to determine the rates to be used. It is anticipated that the information contained in this report will be incorporated into an appendix to CP 112 dealing with structural design in timber to withstand fire.

Objectives

To determine the rate of charring of certain hardwood species suitable for structural use when subjected to standard time-temperature conditions as laid down in BS 476 : Part 1 : 1953.

Materials and Methods

a) Preliminary experiments

Fourteen species of timber, 13 hardwoods together with spruce as a control, were selected. All species were represented by a single block, 150 x 200mm on the exposed face by approximately 50mm thick, except keruing and spruce where duplicate blocks were tested. The species and densities are presented in Table 1. All blocks were conditioned to 12% moisture content before test. Before being attached to an asbestos wood panel placed in the furnace opening, each block was glued with a resorcinol formaldehyde adhesive to a similarly sized block of ramin which acted as a spacer between the asbestos and the test block. The composite blocks were screw-fixed from the back in 3 vertical rows, the ends of which were covered with a 50 x 75 block of softwood to avoid end effects. In all cases, the grain of the test blocks ran vertically. All test blocks were accommodated on two asbestos panels.

Each test panel was in turn sealed into the 900mm square opening of the small fire resistance furnace at the Fire Research Station and was subjected to standard time-temperature conditions for 40 mins. This period was selected as being that which would cause blocks to char for approximately half their depth. At the end of this period the furnace was shut off and the blocks quenched with water. After cooling, the blocks were removed, returned to TRADA, the spacer blocks split off and the remains of the test block allowed to condition in the laboratory. Charcoal was removed by chisel and wire brush. The depth of charring was taken as the difference between the original and residual thickness of the block. Irregularity of charring necessitated visual averaging in some cases.

b) Follow-up tests

The procedure adopted in the second series, involving three fire tests, was essentially the same as that reported above. In this case, however, six blocks of varied origin were used to represent each of six species of hardwood showing low rates of charring in the preliminary tests. Spacer blocks of European redwood were used and the softwood controls were also of this species. In general, two blocks of each species were represented on each panel in a random arrangement. Half the blocks of each species were orientated with the grain running vertically, the rest horizontally to determine what effect this had on the rate of charring. Asbestos wood end stops were used in this series.

Results and Discussion

The results are presented in Table 1. Species are listed in order of decreasing density determined at 12% moisture content. The values in the upper section of the table represent individual determinations, those in the lower section are averages of six determinations. The charring depths were determined to the nearest millimetre and random check measurements gave values within +/- 1 mm of the original measurement. The depth of the residual section was measured in such a way that rounding effects on the arrisses were eliminated. In the blocks which were tested with the grain orientated vertically and where the end grain was not exposed to heat, rounding was restricted to the vertical edges. The limit of charring appeared as a plateau, ending abruptly at the end of the block but falling away gradually near the edges. The top of the plateau was in most cases remarkably flat and measurement with callipers presented no difficulty. Where the surface contained undulations or a longitudinal furrow, the average residual section was determined. In the case of the blocks orientated with the grain horizontally where a large area of end grain was exposed, the rounding occurred in both directions. In blocks with low charring rates, this gave rise to a rectangular plateau but where the charring rates were higher, particularly in the case of controls, the charred surface appeared as a mound. It was the height of this mound which was measured and in most cases the charring rate on these blocks was slightly higher than the overall average.

The reason for this differing behaviour is that the blocks lose moisture as they burn. Shrinkage along the grain is negligible so that the joints between blocks do not open up when end grain surfaces are butted together. With blocks arranged with the grain horizontally in the furnace, the joints between them enlarge as burning proceeds and the effect is that of exposing a block on all four edges. The former situation is the more realistic for most uses of large section timber so that the overall average charring rates are somewhat conservative.

The rate of charring in the preliminary experiments ranged for the high of 0.80 mm/min for abura to a low of 0.425 mm/min for teak. (It is assumed that the rate averaged over 40 minutes represents a steady-state rate of charring). The softwood controls charred slightly less rapidly than the quoted figure (0.56 as 0.56 mm/min)/ When plotted against density, Figure 1, there is a general trend of decreasing charring rate with increasing density but superimposed upon this are individual species variations. Teak, utile, oak and to a lesser extent the spruce, all showed lower charring rates than would be expected from their densities. The replicate control clocks gave almost identical values for charring rate while the difference between the two blocks of keruing can be attributed to a difference in density.

The figures obtained in the first series did not permit generalisations since they are based on a single sample. In most cases, the test block was close to the density quoted for the species (DSIR, 1956). In the second series, attention was focussed on those species which had proved superior in the first tests. In selecting the test blocks, a varied sample was aimed at and in all except jarrah and redwood, where samples all came from TRADA stocks, a variety of sources was represented.

Utile, oak and keruing gave values which were on average very close to those from the preliminary tests. The charring rate for teak was rather low, mainly due to on e block which charred much less rapidly than the others although close in density to the average. Both jarrah and greenheart blocks gave charring rates lower than would have been expected from the preliminary tests, in spite of the densities being similar. In the case of jarrah, the higher rate in the preliminary test may have been due to the presence of surface drying checks.

The range of charring rates given in Table 1. Variation between blocks of the same species shows no relation with density of the individual blocks. No influence of fire test or position on panel was evident. Within a species, the measurement of charring depth was consistent. The method of removing the charcoal (which varied in character with the species) probably resulted in slightly higher estimates of charring rate for the softer species. There is not an abrupt transition between charred and uncharred wood but a gradual change from friable charcoal to undamaged wood. Another complicating factor is the fact that the charring rate is not even over the surface of a block. However, only in a few cases was there pronounced variation which usually took the form of a furrow. In these cases, an average figure for the block was taken. In teak, where this furrowing occurred most often, it appeared to be due to the more rapid burning at the base of the large fissures in the charcoal. The pattern of cracking in the charcoal was characteristic for each species although not apparently related to any obvious timber property. That for teak was of large chunks of charcoal separated by deep fissures; there were often only 4 “chunks” per block.

The charring rate of the controls, based only on the vertical orientated blocks because of excessive rounding on the others, gave values very close to the quoted figure and confirms the validity of the test method.

Conclusions

The rate of charring of certain hardwoods such as teak, jarrah and greenheart was found to be less than 62% of the rate established for softwoods. Oak, utile and keruing gave values of about 80% the softwood figure. These values appear to be consistent for the species and should justify the use of rates of charring different from the commonly used 0.64 mm/min in fire resistance calculations.

Table 1 : Results of charring rate experiments

Species		Density, Kg/m3		Charring Rate, Mm/min	
Greenheart	(Ocotea rodaeii)	990		0.480	
Keruing (b)	(Dipterocarpus spp.)	950		0.525	
Jarrah	Eucalyptus marginata)	850		0.550	
Keruing (a)		790		0.550	
Oak	(Quercus robur)	760		0.500	
Opepe	(Sarcocephalus diderrichii)	730		0.650	
Afrormosia	(Afrormosia elata)	720		0.575	
Teak	(Tectona grandis)	30		0.425	
Iroko	(Chlorophora excelsa)	620		0.625	
Sapele	(Entandrophragma cylindricum)	610		0.600	
Meranti	(Shorea spp)	610		0.650	
Utile	(Entandrophragma utile)	600		0.480	
Abura	(Mitragyna ciliata)	520		0.0800	
Spruce (a)	(Picea abies)	490		0.575	
Spruce (b)		490		0.550	
Khaya	(Khaya ivorensis)	420		0.675	
		Average	**Range**	**Average**	**Range**
Greenheart		1000	991 - 1019	0.381	0.338 - 0.400
Jarrah		870	847 - 900	0.396	0.363 - 0.438
Keruing		775	737 - 794	0.544	0.500 - 0.588
European Oak		722	705 - 740	0.517	0.475 - 0.550
Utile		701	656 - 735	0.523	0.500 - 0.550
Teak		670	620 - 750	0.469	0.375 - 0.513
E Redwood	(Pinus sylvestris)	550	-	0.625	0.600 - 0.650

Figure 1 : The relationship between density and charring rate for fifteen species of timber