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Influence of Thermal Treatment and Impregnation on the Durability of Wood Colour

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Abstract: The effect of thermal treatment and impregnation of woods on the stability of wood colour was investigated. Impregnation was performed by extractives obtained from the same thermally treated species or different ones. Treated and untreated samples were exposed to an accelerating ageing by solar radiation during 1000 h. Results showed that thermal treatments improved mainly the colour stability of softwood (pine and white fir) samples. Analysis of chromatic coordinates after 1000 hours of accelerated ageing showed that, thermally treated pine and white fir woods were the least affected samples with $\Delta E^*_{1000} = 8.66$ and 13.31 respectively. Impregnation increases the component b^* causing an intense darkening of all analysed wood samples. Moreover, impregnation stabilised the colour of poplar and fir woods subjected 1000 hours of accelerated ageing whereas, beech woods showed high variations in colour. Thus, thermal treatment and impregnation could stabilise the surface aspect of woods that have an unstable natural colour. The efficiency of impregnation depends on the nature and physicochemical properties of the extractable substances and thus on wood species.

Keywords: Softwood, hardwood, colour stability, accelerated ageing effect.

1. INTRODUCTION

The use of wood for various applications in joinery depends on its quality and natural durability. Wood surfaces exposed exclusively to weathering decompose very slowly at an estimated rate of 6.4 mm/century. This phenomenon is considered to be superficial since physical and chemical integrities of wood are maintained some layers underneath. Wood is capable of absorbing all wavelengths of electromagnetic radiation; UV-light penetrates approximately 75 μm and visible light approximately 200 μm [1, 2]. However, the main effect of solar radiation on wood is the modification of its chemistry and anatomy that leads to wood discolouration and photodegradation [3, 4].

It was found that, a pyrolysis at a temperature higher than 200 °C deeply modifies the chemical composition of wood although its macroscopic and microscopic organization seem not to be very affected at temperature lower than 300 °C [5]. Moreover, the extractable substances seem to behave like catalysts, at least at the beginning of pyrolysis. Then at high temperatures, they inhibit the reaction of thermal degradation [6]. The quantity of extractable

volatilized, others undergo some significant degradation [7]. Several treatments like drying, impregnation as well as various thermal treatments were proposed and developed in order to stabilize and preserve wood characteristics [8, 9, 10, 11]. Retification of wood is one of the most studied methods [12, 13]. This treatment increases the dimensional stability of wood and improves its resistance to fungi. However, many studies were performed to evaluate the behaviour of treated wood during the process of photoageing under natural climatic conditions or artificial ones [14, 15].

The use of thermally treated woods in the joinery industry depends on the quality and the sustainability of the wood surface. The objective of this work is to study the colour stability of commercial, thermally treated wood samples that are exposed to solar radiation. Because some differences in the durability of wood colour can be observed depending on species, we proposed a method for stabilizing wood colour by using extracts obtained from thermally treated woods of species presenting better characteristics with respect to colour stability.

2. MATERIALS AND METHODS

2.1. Test specimens and heat treatments

Wood samples of 30x30x0.5 mm (longitudinal by radial by tangential) of Vancouver fir (*Abies grandis*), radiata pine (*Pinus radiata*), pine (*Pinus sylvestris*), white fir (*Abies alba*), beech (*Fagus sylvatica*) and poplar (*Populus* spp.) were obtained from the company Asset Drink. Vancouver fir and radiata pine were used as references.

Half of wood samples were thermally treated by retification which was a pyrolysis under inert atmosphere and controlled pressure at 220 °C according to the process NOW (New Option Wood) [15].

2.2 Photodegradation

Untreated control samples and heat treated ones were exposed to photodegradation for 1000 hours. The accelerated ageing of samples was carried out in a SEPAP cell fitted with mercury medium pressure lamps giving an incident flow of 4.5 mWcm⁻² at 366 nm. These mercury lamps are used to simulate the solar radiation in the apparatus [15].

2.3. Extraction and impregnation

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Extractives of thermally treated woods were prepared by defatting of coarsely powdered samples with petroleum ether. Extraction was carried out with a mixture of water: ethanol (30:70 v/v) using a Dionex extractor monitored by the extracting system ASE 200 at pressure of 100 bars in 2 cycles and 100 °C. The static time was 5min.

The rest of the non-treated woods were impregnated under pressure by solution (10 g/L) of extractives according to the process designated as Bethell process [15]. General methods of preparation of wood samples were summarized in Figure 1.

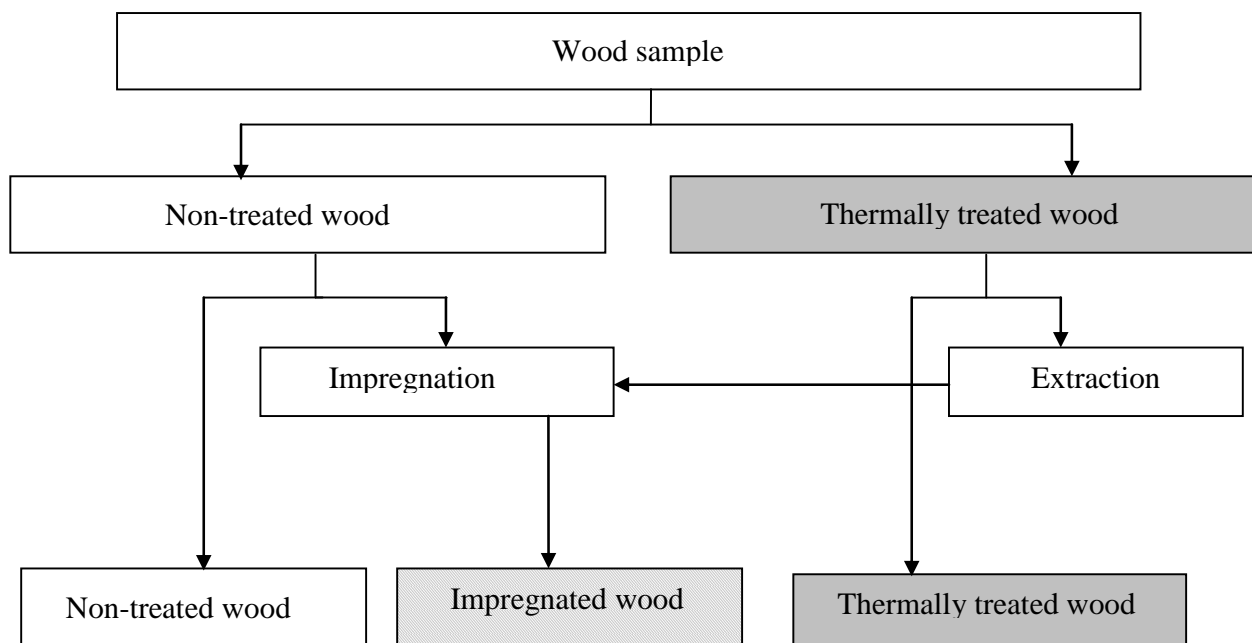


Fig. 1. General schema of experimental procedure.

2.4 Colour measurement

Colour of samples was measured according to CIE $L^*a^*b^*$ system using a spectro-pen Lange spectrometer equipped with an integrating sphere. The CIE $L^*a^*b^*$ system [16] is characterised by three parameters ; L^* , a^* and b^* . L^* axis represents the lightness, it varies from 100 (white) to zero (black), a^* and b^* are the chromaticity coordinates which correspond respectively to green-red and blue-yellow axes (Fig. 2).

The differences in colour coordinates, ΔL^* , Δa^* and Δb^* as well as colour variations before and after treatment or before and after exposure to radiation at different times t were calculated. Each reported value corresponds to a mean of 10 measurements. Colour change ΔE^* was calculated according to the following equation:

$$\Delta E^*(t) = \sqrt{\Delta L^*(t)^2 + \Delta a^*(t)^2 + \Delta b^*(t)^2}$$

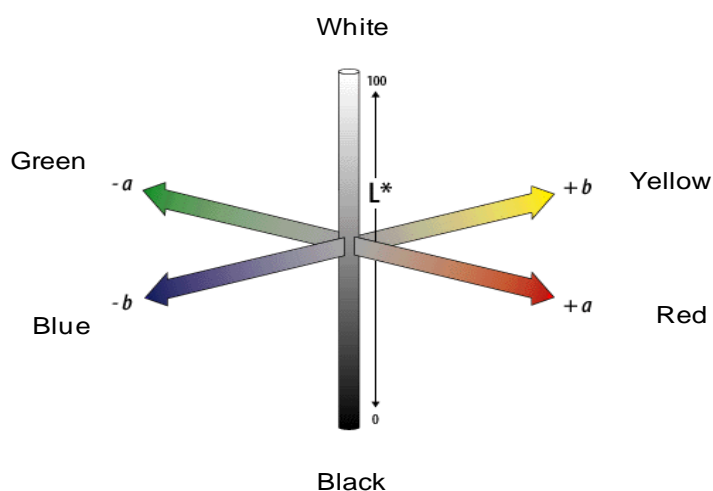


Fig. 2. Colour space CIE $L^*a^*b^*$

3. RESULTS AND DISCUSSION

3.1 Behaviour of untreated (control) and thermally treated woods

The evolution of colour variation during 1000 h of accelerated ageing of untreated wood samples is presented in **Fig. 3**. It was observed that beech sample has the most stable natural colour ($\Delta E^* \approx 7$) whereas poplar and softwoods (pine and white fir) gave the greatest colour variation. Samples of softwoods (pine and white fir) as well as the two control Vancouver fir and Radiata pine exhibited more or less rapid increase on ΔE^* values at the beginning

of the ageing and then a stabilisation after ≈ 200 hours-exposure.

Thermal treatment has a beneficial effect on colour of softwoods samples (pine and white fir) as only very little changes were observed throughout the 1000 hours exposure. Conversely an opposite effect was observed in case of hardwoods samples (beech and poplar wood) (**Fig.4**). Thus, the stability of colour during an accelerated ageing for untreated wood samples decreased according to this order: beech >> poplar > sylvestris pine \approx white fir, whereas, for thermally treated woods decreases according to the following order: sylvestris pine > white fir > beech > poplar.

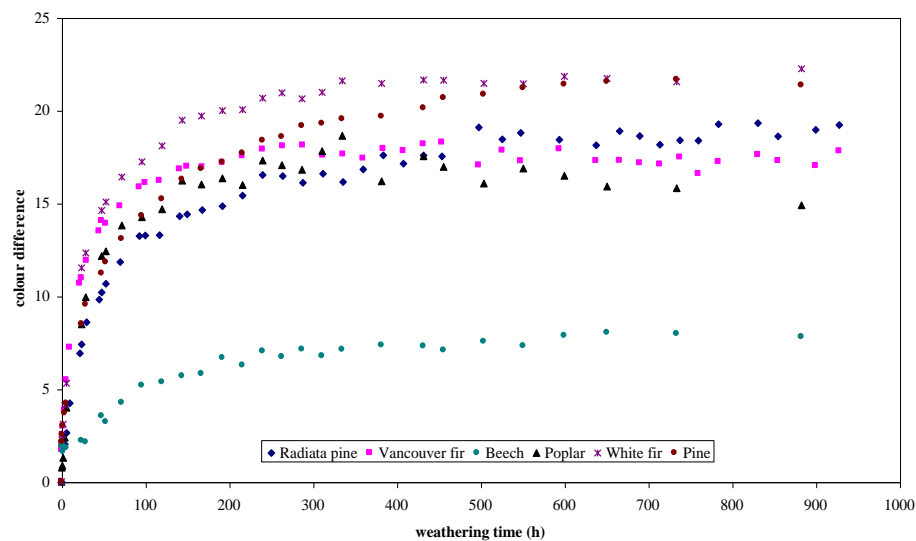


Fig. 3: Colour variation for untreated wood species during accelerated ageing.

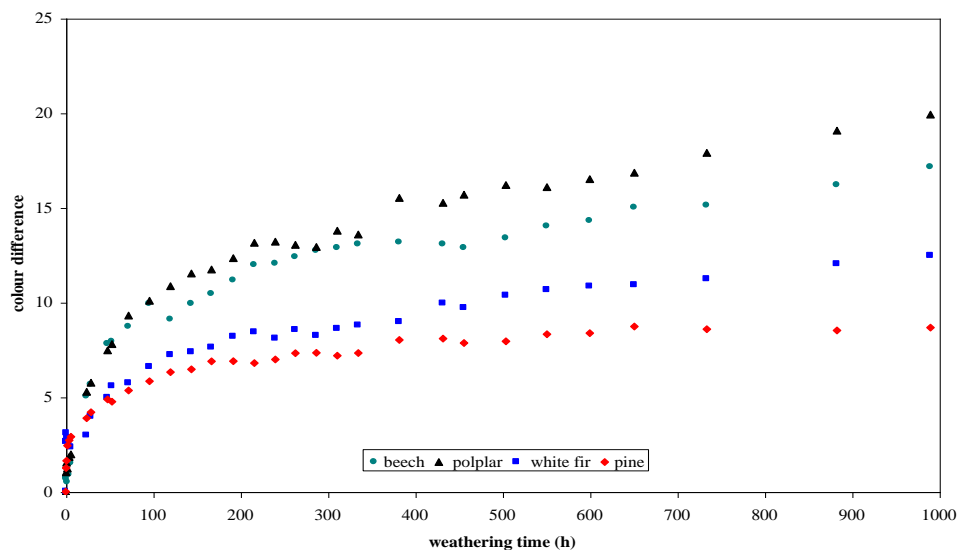


Fig. 4: Colour variation for thermally treated woods during accelerated ageing.

Furthermore, analysis of chromatic coordinates of thermally treated woods showed that, thermal treatment strongly modified the colour of all studied samples on reducing their luminance (decrease of L^* values). Treated beech showed a remarkable decrease in its b^* value and therefore became faint yellow (Table 1).

Analysis of chromatic coordinates after 1000 hours of accelerated ageing showed that, thermally treated woods become clearer and solar radiation causes more yellowing

(an increase of b^* values), which was more noticeable in hardwood (beech and poplar wood) samples. Pine wood was the least affected ($\Delta E^*_{1000} = 8.66$, sample. Interestingly, the a^* values were less influenced by thermal treatment for all samples (Table 2). El bakali et al. [17, 18] showed that changes in wood colour due to the effect of ageing by sunlight was mainly attributed to luminance modification (L^*).

Table 1
Influence of thermal treatment onto the colour coordinates of wood samples.

Wood sample		L^*	a^*	b^*	ΔE^* due retification
Beech	Control	62.68	8.05	20.62	
	Treated	31.75	5.27	6.9	33.95
Pine	Control	82.08	4.22	25.08	
	Treated	44.51	9.79	19.49	38.39
Poplar	Control	85.08	1.76	19.26	
	Treated	40.41	7.67	14.48	45.31
White fir	Control	79.33	5.03	22.01	
	Treated	43.72	8.12	19.31	35.85

Table 2
Variation of chromatic coordinates after 1000 hours ageing for thermally treated wood samples.

Wood sample	ΔL^*_{1000}	Δa^*_{1000}	Δb^*_{1000}	ΔE^*_{1000}
Beech	13.6	0.74	10.41	17.14
Pine	7.44	-0.61	4.38	8.66
Poplar	18.74	-1.49	6.56	19.91
White fir	12.68	-0.23	4.05	13.31

3.2 Extractives of thermally treated woods

It was known that phenolic substances that are deposited in the walls of fibres and vessels and lignified woods contribute largely in the colouring of wood [19]. Untreated and thermally treated woods were subjected to extraction by 70% ethanol and extractives yields are presented in Fig.5. Thermal treatment increased the extraction yields of the studied wood samples and hardwood samples (beech and poplar) produced the highest extract yield than softwood ones (pine and white fir). The quantity as well as the nature of the extractable substances play a significant role in the durability of wood colour and could explain the differences in the behaviour of the different wood species. In fact, thermal treatments do not only affect the extractability of wood substances, but the main macromolecules of wood might be degraded with the formation of non extractable chromophoric groups which could play a significant role on stability of wood colour during the time of exposure to solar radiation [15].

3.3. Influence of impregnation on wood colour

Untreated wood samples were impregnated by extracts of their corresponding thermally treated woods and variations in their chromatic coordinates after colour stabilisation are given in Table 3. Impregnation modified the colour wood samples when compared to thermally treated samples. Variations of chromatic coordinates can be clearly distinguished for both types of treatments. Impregnation increases the component b^* causing an intense darkening of all analysed wood samples whereas thermal treatment lowers this value. Values of chromatic coordinates and ΔE^* , after 1000 h ageing, are also given in Table 4. Very little change in b^* values after 1000 h ageing was observed. The colour of impregnated poplar and fir is markedly stabilised. Conversely, impregnated treated beech woods showed high variations in colour, which might be due to a modification in the nature of extractives after treatment. Thus the stability of colour during accelerated ageing for impregnated woods decreases according to the following order: white fir > poplar > beech.

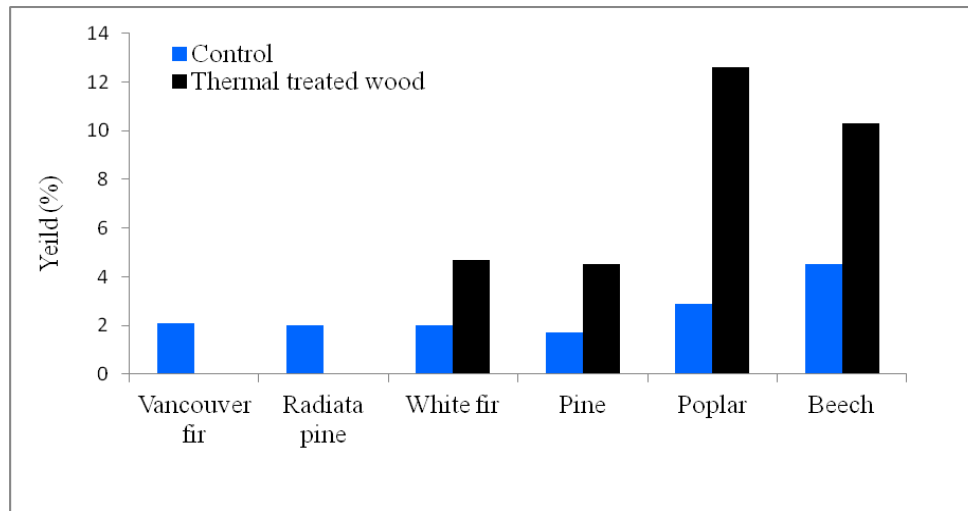


Fig. 1: Extract yield of untreated (control) and thermally treated wood samples.

Table 3
Variation of chromatic coordinates induced by thermal treatment and impregnation.

Wood sample	Treatment	ΔL^*	Δa^*	Δb^*	ΔE^*
Beech	Thermal	-30.93	-2.78	-13.72	33.95
	Impregnation	-12.85	7.04	7.82	16.61
Poplar	Thermal	-44.67	5.91	-4.78	45.31
	Impregnation	-15.59	7.56	9.41	19.72
White fir	Thermal	-35.61	3.09	-2.7	35.85
	Impregnation	-15.31	5.12	10.95	19.51

Table 4
Variation of chromatic coordinates after 1000 hours ageing for impregnated wood samples.

Wood sample	ΔL^*	Δa^*	Δb^*	ΔE^*
Beech	16.32	-5.25	0.99	16.2
Poplar	5.61	-2.12	-1.13	6.10
White fir	-5.05	2.2	0.37	5.52

3.4. Influence of impregnation by extractives coming from other thermally treated species on wood colour

An attempt to see the effect of impregnation, of untreated wood samples with different extractives on colour stability was carried out. Impregnation of beech wood by poplar and fir and beech extracts from thermally treated samples did not improve their colour stability (Fig. 6). Impregnation of poplar (Fig. 7), sylvestris pine (Fig. 8) and white fir (Fig. 9) woods with extracts from thermally treated samples displayed a beneficial effect that stabilised their colour during photochemical ageing. Moreover, impregnation with

extractives obtained from white fir and poplar samples were more efficient than that obtained from beech wood.

These results support earlier studies demonstrating the beneficial role that could be played by natural extractives in the durability of wood colour. Studies on photochemical degradation of fir [20], European oaks [4, 21] and impregnated fir wood by extracts from oak [22] suggested that, phenolic extractable substances limited colour variation caused by an exposure to solar radiation. These substances could play a protective role attributed to their antioxidant properties.

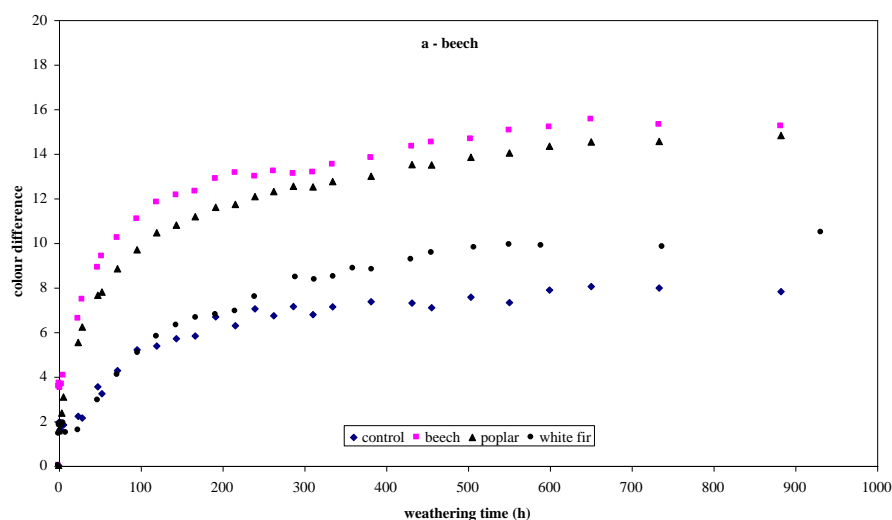


Fig. 6: Photoageing of wood samples impregnated by extracts from thermally treated beech wood.

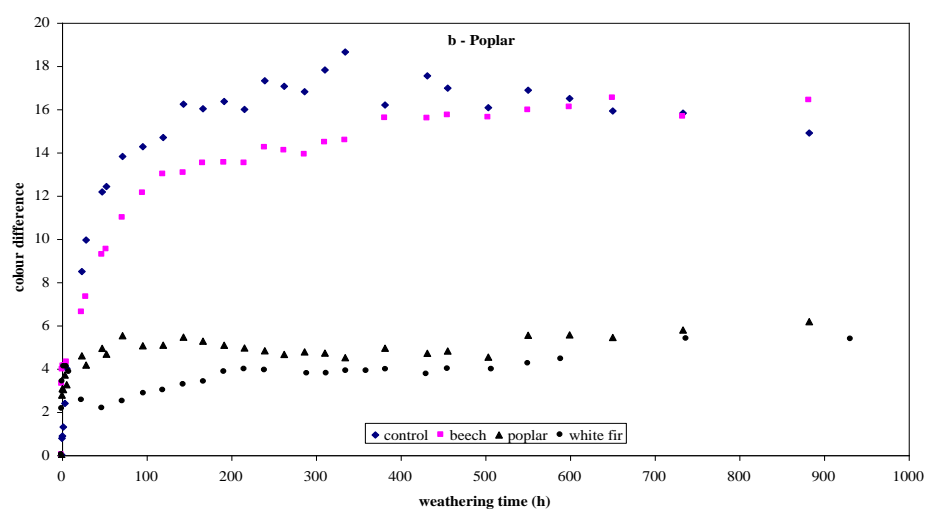


Fig. 7: Photoageing of wood samples impregnated by extracts from thermally treated poplar wood.

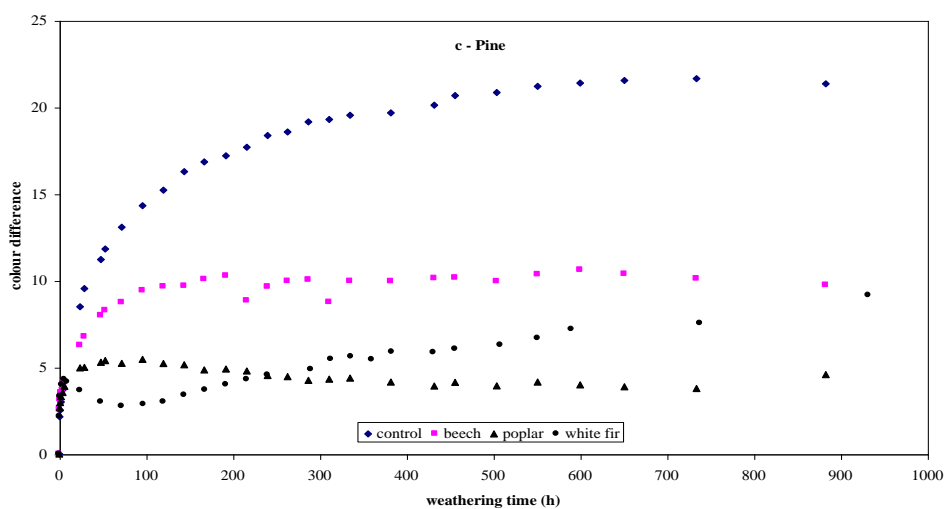


Fig. 8: Photoageing of wood samples impregnated by extracts from thermally treated pine wood.

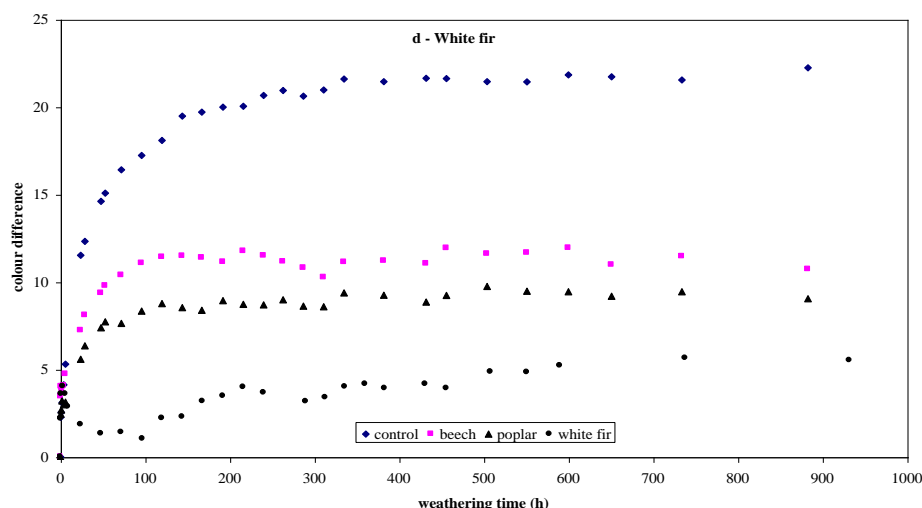


Fig. 9: Photoageing of wood samples impregnated by extractives from thermally treated white fir wood.

4. CONCLUSION

Thermal treatments under controlled conditions tend to clearly stabilise softwoods colour but to a lesser extent the hardwoods one. Impregnation of woods by extractives coming from thermally treated woods could have a complementary role in the colour stability of woods having low colour durability. The efficiency of impregnation depends on the nature and physicochemical properties of the extractable substances and thus on wood species. Qualitative analysis should be carried out to determine the components responsible for the stabilisation of wood aspects.

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