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Seasonal Effects on the Atmospheric Corrosion of Spruce Micro-Sections*

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The results of recent investigations revealed that the atmospheric corrosion (weathering) of micro-sections from spruce was dependent on the season. This was substantiated by the reduction in tensile strength parallel to the grain amounting from 30% in the micro-sections subjected to atmospheric corrosion in April to about 70% in those exposed in July. The decisive factor for the atmospheric corrosion in summer is the intensity of solar radiation, while in winter the increased amount of sulphur dioxide in the surrounding air is the main factor.

Einfluß der Jahreszeit auf die atmosphärisch bedingte Korrosion von Holz-Mikroschnitten

Die atmosphärisch bedinge Korrosion (Bewitterung) von Fichten-Mikroschnitten ist von der Jahreszeit abhängig. Diese Abhängigkeit zeigt sich in einer Verminderung der Zugfestigkeit in Faserrichtung von etwa 30% im April bis etwa 70% im Juli an Proben, die einer atmosphärischen Einwirkung ausgesetzt worden waren. Ausschlaggebender Faktor in den Sommermonaten ist die Intensität der Sonnenbestrahlung, in den Wintermonaten der erhöhte Schwefeldioxydgehalt der Luft.

1 Introduction

Due to its composition and physical properties the atmosphere has corrosive effects on wood and other materials. In comparison with other materials wood in constructions exposed to the action of atmospheric agents has a relatively high resistance to atmospheric corrosion (weathering). The corrosive action of atmospheric agents is limited to the exposed external layers of the wood tissue. Wood degradation under conditions of natural atmospheric corrosion proceeds slowly; it takes almost 100 years before a surface layer of about 10 mm is eroded (Wood Handbook 1974; Raczkowski 1978; Feist and Mraz 1978). Wood develops a protective layer retarding the penetration of corrosive agents into the wood tissue. When wood is exposed to the action of atmospheric corrosion in the absence of the destructive action of microorganisms it is serviceable for several hundred years (Borgin 1971).

Research carried out until now on the natural atmospheric corrosion of wood payed relatively little attention to the course of wood disintegration and destruction in its surface layers in relation to the mechanical properties of these layers. Earlier observations of thin wood sections of about 100 µm thickness revealed that the destruction of wood tissue resulting from natural atmospheric corrosion proceeds quickly and penetrates relatively deep and that the decrease in the mechanical strength properties is very significant (Raczkowski 1978). Solar radiation in the presence of oxygen and water produces photolysis of the chemical cell wall components (Sandermann and Schlumbom 1962; Futo 1974). The anisotropic character of deformations caused by changing moisture and heat conditions in particular layers of the cell walls results in the development of stresses reducing the cohesion of the wood substance and ultimately leads to the decrease in strength properties or even to the total disintegration of the structural components of wood.

Considering the obvious lack of experimental data on the process of atmospheric corrosion in the surface layers of wood and its effects on the mechanical properties of these layers, it was decided to carry out several experiments concerning the seasonal effects on the process of the atmospheric corrosion of wood. The immediate aim was to determine the atmospheric corrosion of micro-sections in relation to the months of the year, by measuring the tensile strength parallel to the grain.

2 Methods

Tests were carried out, using samples of spruce (Picea abies Karst.) from the Jordanów forest stand of a III/IV site class situated at Sucha Beskidzka. A 40-cm-long bolt was cut at a distance of 3 m from the stump of a 50-year-old trunk. The scheme of sampling is presented in Fig. 1.

Samples were prepared from the growth zone between the 25th and the 29th annual ring. The mean width of these rings was about 2.5 mm with a mean proportion of 26% of summerwood. The wood density approximated 450 kg/m^3.

Experiments were carried out on wood micro-sections with the aim of studying any fast and serious changes in the wood due to the action of atmospheric agents. Such sections had already been used successfully for investigating the resistance of wood against biological corrosion (Kennedy and Ifju 1962) and against chemical corrosion (Manwiller and Godfrey 1973) as well as against atmospheric corrosion (Raczkowski 1978).

Using a sliding microtome, sections of 4.5 mm × 30 mm × 110 mm in radial, tangential and grain directions were prepared from wet strips of wood. Care was taken that the sample sections were not damaged by the cutting process (Biblis 1970; Helińska-Raczkowska and Raczkowski 1978). After initial visual screening of the prepared sections only those without cutting defects and with ideal orientation of the longitudinal tracheid axis in relation to the axis of the sample were selected and used for the experiments.

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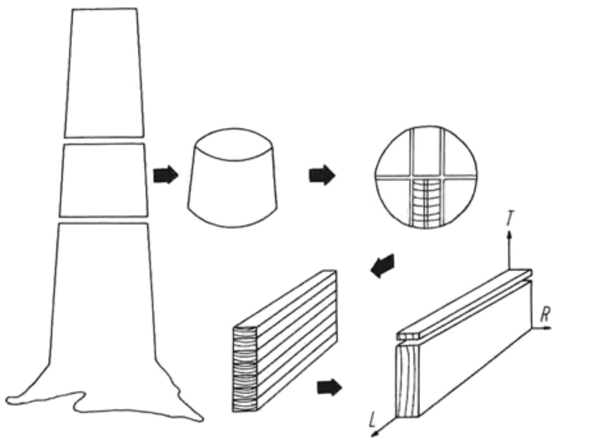

Fig. 1. Preparation of the specimens. *L* longitudinal, *R* radial, *T* tangential

Bild 1. Probenahme und Probenzuschnitt. *L* Längsrichtung, *R* bzw. *T* Radial- bzw. Tangentialrichtung

Table 1. Tensile strength parallel to the grain of spruce micro-sections exposed to atmospheric corrosion

Month	Statistical values			
	n	$\bar{x} \pm m$ MPa	$\pm\sigma$ MPa	V %
1977 April	25	156 ± 6.5	32.3	20.7
May	25	127 ± 8.7	43.5	34.2
June	25	89 ± 5.0	25.2	28.4
July	20	60 ± 5.1	22.8	38.0
August	25	66 ± 4.2	20.8	31.8
September	25	76 ± 3.4	17.2	22.7
October	23	99 ± 4.4	21.2	21.3
November	25	103 ± 5.4	26.8	25.9
December	25	110 ± 4.8	24.2	22.0
1978 Januar	25	97 ± 5.2	26.0	26.7
Februar	25	94 ± 3.8	19.0	20.3
March	25	86 ± 2.9	14.5	16.9
Control samples	25	211 ± 8.7	58.6	28.0

n number of samples tested
$\bar{x}$ arithmetic mean
$\pm m$ error of the arithmetic mean
$\pm\sigma$ standard deviation
V coefficient of variation

The nominal dimensions of the flat rectangular microtome sections were: thickness in tangential direction 0.1 mm; width in radial direction 4.5 mm; length in longitudinal direction 110 mm. The width of the sample comprised about two annual rings. The ratio of the external surface of the samples to their volume guaranteed a sufficiently high action of atmospheric agents on the wood tissue. It is known that the natural ultraviolet rays penetrate into the wood up to a depth of 50–100 µm (Sell 1975) so that the total thickness of the samples investigated would be penetrated.

The experiments on the effects of atmospheric corrosion were carried out under the natural conditions prevailing in Poznań between April 1977 and March 1978. In order to eliminate the effect of ground surface micro-climate (Barton 1976), the specimens were exposed on the flat roof of the building at a height of about 15 m from the ground level. The samples were mounted in separate cassettes, each containing 25 sections, with the large surface of each sample being directly exposed to the action of atmospheric agents over a length of 50 mm, while the two remaining ends of 30 mm length were shielded. The lower edge was about 50 cm away from the roof surface. Western winds prevail at this test site. In the immediate vicinity, no industrial plants are situated in this direction. The test site was not sheltered; it was exposed to the action of sunlight, rainfall and winds. A container was installed next to the rack to collect rainwater, the pH of which was measured periodically. Data concerning insolation were supplied by the Meteorological and Water Management Institute, Poznań, about 3 km away from the test site. Data on the Sulphur-dioxide-content of the air were obtained from the Poznań-Sanitary and Epidemiological Station from sites about 1 km away from the experimental site.

Tensile strength along the grain was used as the main criterion for measuring the resistance of wood against atmospheric corrosion.Tensile tests were carried out,by using samples which had been exposed for one month in each season. In addition, the tensile strength of control samples which had not been exposed to the action of atmospheric agents was determined. The samples were conditioned before testing in the Mytron-KPW-1 conditioner for 14 days under conditions of 293 ± 2 Kelvin and 65 ± 5% relative humidity. The samples were tested in an Instron testing machine with a loading capacity of 10–50 N. The loading speed was 0.5 cm/min and the speed of the registering band was 5 cm/min. Before testing, the width and the thickness of the samples were measured with an accuracy of 0.01 mm.

3 Results

The results of the tensile strength tests along the grain of spruce micro-sections after exposure to atmospheric corrosion for 30 days during different seasons are presented in Table 1.

As can be seen from this table, only in three instances the variability coefficient of the tested strength exceeded 30%. The tensile strength along the grain determined on micro-sections slightly increased the variability in comparison with the strength of standard samples ($V = 20\%$ according to ISO/DIS 3129). The diagram in Fig. 2 shows the effects of natural atmospheric corrosion on the tensile strength of micro-sections during particular months of the year. In the upper part of this diagram the decrease in tensile strength of the samples exposed to atmospheric corrosion for a given month is shown in comparison with the strength of control sections calculated from the following equation:

$$\Delta R^{+} = \left(1 - \frac{R_m^{+}}{R_0^{+}}\right) 100\%$$

where R_m^{+} is the strength of sections exposed to atmospheric corrosion for a given month, R_0^{+} is the strength of the control sections. The centre part of the diagram (Fig. 2) indicates the mean monthly insolation period, and the lower part presents the average pH value of the rainwater during the period investigated.

From the curves in Fig. 2 it can be deduced that the maximum decrease in tensile strength parallel to the grain amounting to more than 60% of the strength of the control samples is characteristic of sections exposed to atmospheric corrosion during the summer months. A somewhat lower decrease in strength, i.e. in the range from 50–60%, is observed with samples exposed to the action of atmospheric agents during the autumn and winter months. The lowest decrease in tensile strength amounting to 40% or less, as compared

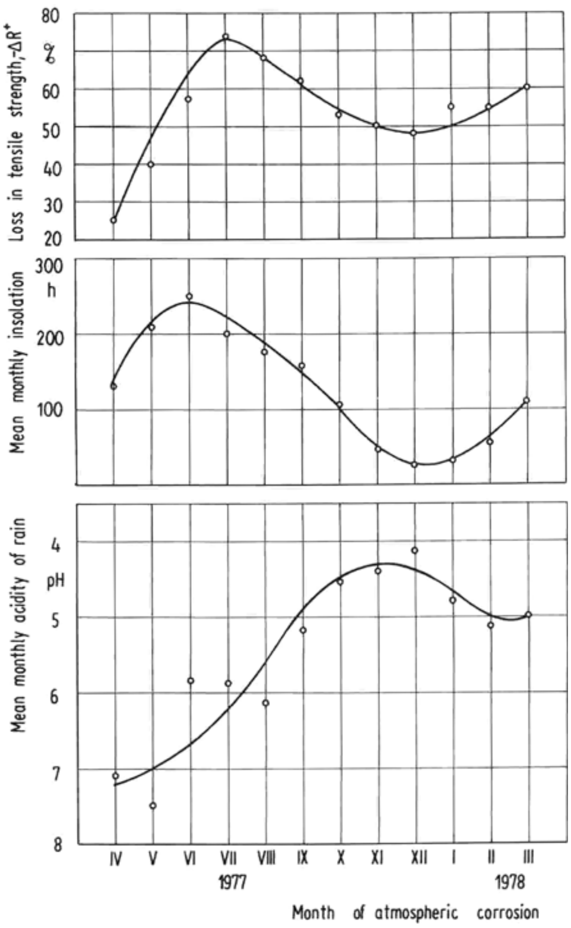

Fig. 2. Relationship between the loss of tensile strength of spruce micro-sections, the mean monthly insolation and the acidity of the rain water

Bild 2. Zusammenhang zwischen der Zugfestigkeit parallel zur Faser der Mikroschnitte und der monatlichen Sonnenbestrahlung bzw. des Säuregehalts des Regenwassers

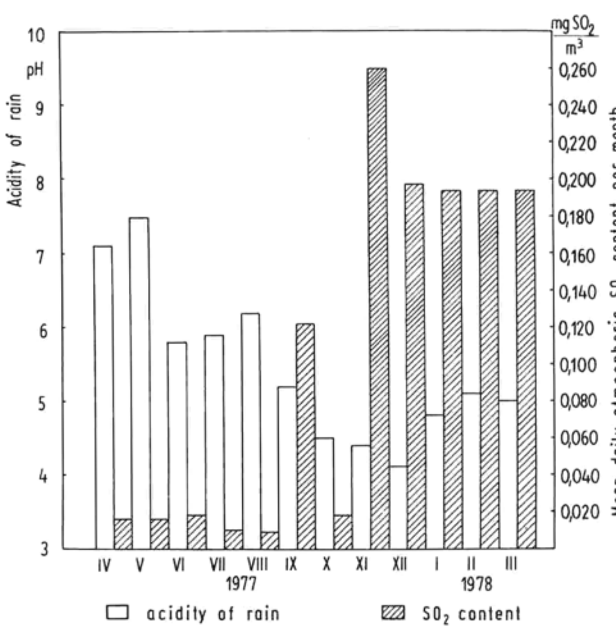

Fig. 3. Mean monthly acidity of rainwater and mean daily sulphur-dioxide in the air during one month

Bild 3. Mittlere Monatswerte des Säuregehalts des Regenwassers und mittlere Tageswerte des Schwefeldioxid-Gehalts der Luft während des jeweiligen Monats

with the control samples, was observed with samples exposed to atmospheric corrosion during the spring months. It can therefore be concluded that the destruction of microtome wood sections due to atmospheric corrosion is a rapid process, the intensity of which depends on the season.

The course of curves illustrating the decrease in strength of the micro-sections in relation to the month of exposure as well as the curves showing the insolation values and the pH of the rainwater suggest the existence of interesting relationships. This indicates that among the atmospheric agents detrimentally affecting wood under certain conditions, insolation and pH of rainwater are the most significant. Especially the pH of the rainwater indicates the presence of aggressive gases in the air, the so-called acid gases. This presence can be attributed to the sulphur-dioxide-content of the air surrounding the experimental site (Fig. 3). The sulphur dioxide content of the investigated atmosphere and the resulting acidity of the rainwater markedly increase during the autumn and winter months due to the emission of combustion gases and smoke in the heating period. The sulphur dioxide content during this period varies from 0.005 to 0.264 mg/m^3 in the course of a day (24 h) which is characteristic of the atmosphere in urbanised, but not industrialised areas (Kutzelnigg 1957). Sunlight, particularly the ultraviolet rays, actively destroy wood and most other organic substances. Because of its energy solar radiation can initiate photochemical reactions (Greathouse and Wessel 1954). Photolysis of wood proceeds all the more rapidly, the more agents, such as oxygen, water, heat etc., are involved in the process where significant changes occur in lignin as well as in the carbohydrate components of wood (Sandermann and Schlumbom 1962; Sell 1973; Futo 1974). Since tensile strength of wood parallel to the grain is mainly dependent on the cellulose (Klauditz, 1952), the reasons for this decrease in strength should be investigated, primarily by studying the degradation process of cellulose. In the photodestruction process the degree of cellulose polymerisation decreases, while the share of low-molecular fractions containing carboxyl and carbonyl functional groups increases (Greathouse and Wessel 1954; Flate 1976). The deterioration of wood by solar radiation varies at the same latitude and depends on the season and other factors.

During the summer months the reactions of photolysis are greatly accelerated because solar radiation is much more intensive in comparison with autumn and winter. The intensity of UV-radiation is greatest during the summer months (Luckiesh et al. 1937). These observations therefore justify the statement that solar radiation during the summer months is a dominating factor contributing to the natural atmospheric corrosion of spruce micro-sections. The importance of insolation in the process of atmospheric corrosion of wood was also demonstrated by Kaneda (1977) who found that plywood exposed southwards suffered a 50% higher reduction in strength compared with results of the same material exposed northwards. The reduction in tensile strength of wood samples exposed to atmospheric corrosion during autumn and winter is, however, more significant than should be expected, taking into account the mean insolation in particular months of the period. It seems as if the greatly increased sulphur-dioxide-content during this period (Fig. 3), which is corroborated by a markedly increased acidity of the rainwater, constitutes another active factor in the process of atmospheric corrosion of wood. Sulphur-dioxide is a typical air-polluting gas in urbanised and industrialised areas emitted into the atmosphere due to the increased burning of various fuels containing sulphur – particularly of coal. Sulphur dioxide also actively accelerates corrosion because it is easily soluble in water (16.2g SO_2 in 100g H_2O) (Bartoň 1976). This gas is one of the principal factors contributing to the destruction of paper and other cellulose-based materials (Greathouse and Wessel 1954; Flate 1976). An example for the accelerated deterioration of paper by increased amounts of sulphur-dioxide in the air was described by Kimberley and Scribner (1937). They observed that the paper of books which were stored for longer periods in municipal libraries was more quickly deteriorated than the paper of books of the same editions stored in rural libraries.

Race (1949) demonstrated that in highly industrialised towns, such as Leeds (Great Britain), cotton yarn exposed to the action of atmospheric agents revealed an increased reduction in tensile strength during the winter months when the air was more polluted by combustion gases emitted due to intensive heating of apartment houses. During the winter months, a distinct tendency to fog accumulation can also be observed, and this leads to a critical concentration of acid air components. In other months the movement of atmospheric air dissipates gaseous components which results in a local decrease of their concentration.

The results and the data cited indicate that in the process of natural atmospheric corrosion of spruce micro-sections taking place during the autumn and winter months, the increased amount of sulphur-dioxide in the air is a dominant factor. The process of wood degradation under the conditions investigated is, of course, accompanied by the presence of other active chemical components and physical factors of the atmosphere, particularly of frequent changes of temperature and relative humidity (Raczkowski 1978).

During all months of the year the exposed sections displayed characteristic discolourations. In the spring and summer months a characteristic brown discolouration typical of ligno-cellulosic materials was observed due to the action of solar radiation. In autumn and winter a greyish discolouration dominated. The samples inspected did not display any visible effects of biotic agents.

The results further indicate that the destruction of the superficial layers of wood up to a depth of about 50 µm is rapid and intensive during the initial 30 days of exposure to atmospheric corrosion.

4 Conclusions

1. Atmospheric corrosion of spruce micro-sections is influenced by the season. This fact is substantiated by a reduction in tensile strength by about 30% in April to about 70% in July.

2. During the summer months changes in wood structure, expressed by the reduction in tensile strength, are more intensive in comparison with autumn and winter.

3. A dominating factor in the process of atmospheric corrosion of micro-sections during summer is intensive insolation, while during autum and winter it is the increased amount of sulphur-dioxide in the air.

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