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Preface

Fire safety for timber buildings and structures is the issue of the day in view of the new momentum this construction industry sector is gaining and the boom in novel technologies and timber materials.

The engineering idea behind this book is based on the concept we have embraced: Timber is a natural composite, and its behavior in fire conditions and fire resistance depend both on its physical structure (morphology) and features of its chemical structure as well as material chemical composition.

This has determined the principle of the book's arrangement and its division in three parts.

The first part (Chaps. 2, 3, 4, 5, 6, and 7) contains data on the structure and properties of various timber species and examines their behavior under high-temperature heating and response to fire. We show the effect of temperature and moisture on the thermal, physical, and mechanical properties of timber. We present the results of experimental and theoretical studies of pyrolysis, ignition, heat release, flame spread, and generation of smoke and toxic combustion products of various timber species. We offer the original form of presenting lower complete combustion heat of timber as a function of its chemical composition. This allows us to determine the lower complete combustion heat values for extractives and hemicelluloses into individual timber species.

The second part of the book (Chaps. 8 and 9) addresses the issues of fire safety, fire resistance, and fire protection of construction members of timber buildings and structures. We present an approach to the fire safety system in buildings and assessing the temperature regime during a fire. We show an engineering way to predict the time of the achievement of critical values of fire hazards factors (temperature, smoke, toxic gases, oxygen deficit) at the initial stage of fire development in a compartment with timber linings. We present data on the charring rate in timber structural members and properties of the char surface layer. We also describe modern trends in enhancing fire safety and fire resistance of timber structures. This part presents a detailed analysis of the fire-protection efficiency of two types of systems: impregnation compositions and intumescent coatings, where the latter is produced from plant raw material and is free of additional fire retardants.

We show the effect of fire-retardant impregnation on the charring parameters of timber structural elements in standard fire regime.

The third part of the book (Chaps. 10 and 11) presents our original data concerning the effect of long-term natural (up to 700 years) and artificial aging of deciduous and coniferous timber species on fire safety characteristics. We address to transformations in physical structure, chemical composition, and properties of timber during natural aging of timber buildings and structures. We provide analysis of the effect of aging on timber charring parameters and properties of the charred layers formed during a fire. The process of biodegradation of timber constructions and the efficiency of a new bio-moisture fire-protective composition is also examined.

This part describes an artificial aging method producing the equivalent to timber buildings that have been in service for up to 500 years. It is accompanied by experimental results of thermal and chemical analysis of timber specimens artificially aged to 150 years showing the change in the fire safety indices.

We would like to express our gratitude to Professor, Dr. Fyodor Shutov for his interest in our work, assistance, fruitful discussions, and valuable remarks.

Moscow, Russia

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Contents

Chapter 1
Introduction

Abstract This chapter presents the detailed description of the main timber species applicable in construction industry. Numerous statistical data related to the fire cases in the twenty-first century are discussed (basically in Russia). These data emphasize that the timber and timber products are the main reason for most of the fire cases in timber buildings and structures. The original approach for understanding the fire behavior of timber of different species has been developed: the intensity of fire is a complex function of several interrelated parameters such as chemical structure, physical morphology, technical properties, age of timber constructions, and intensity of external heat flow.

Forests are the primary source of timber. Russia is one of the most forested countries in the world. Almost a quarter of our planet's forests grow on its territory. With a relatively small number of main tree species, we observe great intraspecific variety. The main species usually include those occupying more than 0.1 % of the forested area. They include six coniferous and 13 domestic leaf species (Ugolev 2001). However, a large number of subspecies, varieties, climatic populations, clones, spontaneous crossbreeds, and other biological forms of these main species have been distinguished and described (Ugolev 2001; Kalutskiy 1982).

The formation of rich intraspecific tree polymorphism was facilitated by our country's enormous area; vast forest range; different combinations of soil, hydrologic, and climatic conditions; and many other factors (Shirnin 2004).

It should be borne in mind that the forest ecosystem plays the key role in generating oxygen for the Earth's atmosphere. By also having other environmental (water and climate regulating) functions, it actually determines the condition and survival resources of modern civilization (Kuznetsov and Baranovskiy 2009).

The species composition of Russian forests varies considerably from north to south and from west to east in our country. On the whole, coniferous forests prevail. However, their percentage changes from north to south with consideration of the amount of woodland in different regions. Thus, the percentage of coniferous in the

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boreal forest is almost 80 %. They occupy about half of the forest stands in the mixed forest area. In the forest-steppe zone, coniferous forests cover a 25 % of woodlands, while in the steppe regions, they occupy only 12 % of forest lands.

Soft deciduous species like birch, aspen, and lime prevail among in the mixed forest area. In the forest-steppe area, mainly hard deciduous species prevail, with oak being predominant (Kalutskiy 1982).

The main forest-forming coniferous in Russia are larch, pine, and fir trees. Larch forests occupy 2/5 of the country's forest land and account for a third of the timber resources. Up to 14 different larch species grow in Russia. Their areas are geographically separated. In the northern limit of the forest ecosystem (subarctic area), Dahurian larch (Gmelin) and Cajander larch are absolutely dominant. It is assumed that during evolution these larch varieties acquired the features allowing them to adapt to extreme frozen ground conditions as well as to fires (Benkova and Benkov 2004).

Tree species such as the Dahurian larch (it occupies 56 % of the area of larch forests), Siberian larch (13.9 %, respectively), and Sukachev larch (total of 0.1 % of woodlands) have the greatest national economic value (Ugolev 2001; Chakhov and Lavrov 2004). Larch-based materials are widely used in civil and industrial construction. Due to their increased decay resistance, they are used in hydrotechnical structures. Like other species, they are also used in the most varied areas of the national economy.

Pine forests rank second among coniferous in abundance, occupying 1/6 of the country's forests, while fir forests rank third (about 1/8 of the area, respectively). Other main coniferous species, in addition to the above-mentioned, include cedar (as well as the Pinus pine), silver fir (Abies genus), and yew (Taxus genus).

Although deciduous forests occupy only 1/5 of our country's forests, they are characterized by greater variety than coniferous ones. Oak (Quercus genus), beech (Fagus genus), ash (Fraxinus genus), lime (Tilia genus), maple (Acer genus), birch (Betula genus), aspen and poplar (Populus genus), elm (Ulmus genus), alder (Alnus genus), walnut (Junglas genus), and others have commercial value for manufacturing various products (Ugolev 2001).

Studies of the variety of morphologic tree species forms in natural forest populations based on the nature of the plants' genetic constitution and genetic conditionality increased rapidly in the second half of the past century. These studies are the scientific basis for the development of applied areas of forestry, have great practical importance for solving problems of breeding timber plants, and for improving timber productivity and quality. The interaction of a certain plant genotype with the growth habitat conditions and the impact of genetic and environmental factors on timber structure, chemistry, and properties (distinctive features) are of special interest here (Rone 1980).

Tree genotypes have individual responses to environmental influence. Tree biometric parameters are most often used as external plant features dependent on hereditary factors. Tree growth parameters are used (in particular, the beginning and end of growth and the ratio of spring and autumn wood in annual rings) to analyze the biological effects of interaction in the genotype–environment system.

Wood strength properties are used as an indication of wood quality. The amount of data on physical and mechanical properties of many tree species from different regions of world countries has increased recently. It is shown that wood's physical and mechanical properties are under strict genetic control. The share of genotype influence on various physical and mechanical properties of timber, e.g., of poplars from the Lower Volga floodplain, reaches 47–77 % (Shirnin 2004).

It is notable that quantitative analysis of purely genetic effects of the development of tree populations considers some biochemical features as well. In particular, data on the number of isoperoxidases in fir needles, as well as on monoterpene content in pine needles, have been successfully used for this purpose (Rone 1980; Baumanis et al. 1978).

Forest woody populations, like other higher green plants, are remarkable living forms having immense biosynthetic capabilities. By consuming water and carbon dioxide, microelements and simple inorganic nutrients providing the plant with only six elements, namely, carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus, they are able to synthesize all of the complex organic substances required to make the components of plant tissues, for tree growth and reproduction. Sunlight is the primary source of energy for biochemical synthesis processes.

At present, extensive data have been accumulated on the anatomical organization and microstructure of various tree species and kinds as well as plant tissue chemistry.

Biochemical genetics of woody plants on the molecular level is the least studied wood science. However, on the basis of available data, the scientific community is already coming to the conclusion today that evolutionary development of woody plants and their natural selection and adaptation are primarily controlled by molecular mechanisms, and only then are determined by ambient conditions. Environmental stresses to a greater or lesser extent affect biosynthesis of the main chemical compounds and so-called metabolites and change the percentage of chemical components in timber.

Timber is a combustible material, like any other organic substance. Timber combustion is primarily a chemical oxidation-reduction process characterized by material degradation, heat liberation, and the formation of various reaction products. But the process of combustion onset, spread, and damping is very complex. It is a combination of both chemical reactions and many purely physical processes (phase transitions, diffusion, heat exchange, mass transfer processes, etc.). For this reason, in order to understand the mechanisms of timber ignition and combustion, and its fire-hazardous characteristics, in addition to knowledge of the chemistry and quantitative content of the main chemical components, one also needs data on the specific features of the timber's texture and its thermophysical and other properties. The nature of thermal impacts on timber-based materials, as well as its operating environment, is very important.

Timber was in fact the first object of an organic polymeric nature used to study the patterns of combustion in solid condensed systems as well as the factors affecting this process. At first, these studies were of a purely empirical nature. They were prompted by the wish to make the most effective use of wood as fuel.

Table 1.1 Effect of fire-resistance rating and building footprint (S, m^2) on the number of fires and human deaths in 2000

Building fire-resistance rating	Building footprint, S, m^2							
	Up to 25		25–100		101–500		More than 500	
	Fires	Deaths	Fires	Deaths	Fires	Deaths	Fires	Deaths
I–II	302	18	97	9	47	2	7	0
III	898	14	448	11	397	6	113	55
IV–V	2,907	67	2,848	60	2,582	95	448	82

Even in the first half of the twentieth century, timber provided most of the total thermal energy consumed in many industrially developed countries (Dunkerely 1980). Timber was attractive because it was a cheap and renewable thermal energy source. At present, timber is a raw material for making many valuable substances and materials, and active efforts are underway to create new technologies for producing gaseous and liquid biofuels from wood. However, the issue of timber's fire safety and the creation of the essential principles of its combustion process and fire protection have come to the forefront.

Global fire statistics shows that fires related to burning forests and timber-based and other organic materials in various kinds of structures pose a real hazard to modern civilization, adding to destabilization of life on our planet (Brushlinskiy et al. 2007). About 6.5–7.5 million fires are registered annually throughout the world, causing the death of 70,000–75,000 people and injuring about one million people. It has been determined that 35 % of all fires occur in buildings, in the majority of cases in residential buildings. Furthermore, the most destructive character of fires with a large number of dead and injured persons, as well as significant material damage, occurs in buildings with timber structures (buildings with fire-resistance rating IV–V). This is obvious from statistical data on fires in Russia for 2000 (Table 1.1) (Data on fires and their consequences for constituent entities of the Russian federation 2000).

Many Russian regions are still characterized by a large area occupied by buildings and structures with fire-resistance rating IV–V (Karelia, Republic of Komi, Arkhangelsk, Vologda, and other regions where timber is a traditional building material).

The observed situation with fires involving timber is not surprising. Chronicles of peoples from various countries include multiple examples of not only huge forest areas destroyed by fires but also of whole cities, which required years of painstaking restoration work. Thus, Moscow's timber buildings were completely burned in 1176. The fires of 1331 and 1337 destroyed the wooden Moscow Kremlin. Even today, forest fires cause enormous damage and destroy the living ecological environment. According to (Fires and fire safety in Russian Federation for 2007–2011 years 2012), as of November 1, 2011, forest fires in the Russian Federation affected millions of hectares of land, destroyed millions of cubic meters of standing forests, and eliminated significant areas of young forests (Table 1.2).