WOOD PROPERTIES OF MAIN TREE SPECIES
FROM PLANTATION IN CHINA

中国
主要人工林树种
木材性质

鲍甫成　江泽慧　等著
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建设林业
两大体系
攀登木材
科学高峰

徐有芳

林业部部长徐有芳于 1997 年 1 月为本书题词。

Establishing integrated forestry ecological system and advanced forestry industrial system, and scaling new heights in wood science.

Xu Youfang

the Minister of Forestry, P. R. China

January 1997

序

　　林业是国民经济的重要组成部分，既是基础产业，又是社会公益事业，肩负着优化环境和促进发展的双重使命。森林作为陆地生态系统的主体，是人类发展不可缺少的重要自然资源，在改善生态环境、维护生态平衡、实现可持续发展中具有不可替代的作用。

　　我国是一个少林国家，且分布不均，质量不高，人均林地面积、森林蓄积量和木材消费量只占世界人均水平的 17.2％、12％和 17.6％。目前，全国现有天然用材林中，可采资源濒临枯竭。随着经济建设的发展，人口的增加和人民生活水平的提高，一方面对木材的需要量与日俱增，年需求量约 2.5 亿 m^3，出现高达 5000 多万 m^3 赤字，占总需求量 20％的木材不能供给，严重影响经济建设；另一方面我国木材产品精加工、深加工少，木材综合利用率低，仅为 40％，与林业发达国家的 80％相比有很大差距，木材资源的严重浪费，进一步加剧了木材供求矛盾。当前我国面临的水土流失、土地沙化、水资源短缺、物种减少等突出的生态环境问题和频繁的水、旱、风等自然灾害，都与森林总量不足、分布不均、质量不高密切相关。

　　植树造林，绿化祖国，扩大森林资源，改善生态环境是我国的一项基本国策。1992 年联合国环境与发展大会后，我国政府把林业可持续发展作为长期的发展战略目标，列入《中国 21 世纪议程——林业行动计划》，并在推进林业生态工程建设、森林培育、保护和利用、荒漠化治理、生物多样性保护、山区开发与脱贫、林业产业发展等领域采取了一系列重大行动，取得了显著成效。特别是近几年，我国森林资源发展开始实现了森林面积和森林蓄积的双增长，全国人工林保存面积累计已达 3425 万 ha，其速度与规模均居世界第一，出现了前所未有的发展态势。但从总体上看，我国林业发展仍存在着数量与质量、供给与需求、管理与效益的突出矛盾，面临着建立比较完备的林业生态体系和比较发达的林业产业体系的长期战略目标的艰巨任务。应当指出，自 60 年代以来，我国在营造人工林时忽视了木材性质与营林培育关系的研究，未能按照木材最终用途对木材的要求营造人工林并实行定向培育，以致现已成林的木材难以适应市场的需求；另外，对这些已成林的木材在加工利用时忽视了木材性质与加工利用关系的研究，未能按照人工林木材材质材性的特点进行科学加工、合理利用，从而导致现已成林的木材难以发挥应有的效益。

　　木材科学，作为营林培育科技进步的依据和木材加工利用科学技术提高的前提，是人工林培育和利用的基础。国内外森林培育和利用的实践证明，以木材科学研究为基础，方

可实现林木定向培育和木材高效利用。随着我国木材资源结构性的变化，逐步从利用天然林木材为主向以利用人工林木材为主过渡，这就向木材科学提出了新的挑战，要求木材科学给予人工林的营林培育和加工利用以有效的科学指导。这是新时代赋予木材科学研究的使命。

《中国主要人工林树种木材性质》一书，正是在新时代赋予的使命下应运而生。它是全国 7 个科研院所、高等院校的 50 多位木材学专家经过整个"八五"期间的奋力攻关，以国内外木材科学领域前所未有的广度和深度，对我国主要人工林树种木材性质全面、系统、深入地进行了多树种、多地域、多领域、多内容的广泛研究，是一部与人工林林木定向培育和木材高效利用紧密结合的木材性质研究专著。它既可为研究人工林林木良种选育、集约经营、定向培育新技术提供科学依据，又可为研究人工林木材科学加工、优化工艺、高效利用新技术提供科学指导。它的面世，标志着我国木材科学研究进入了一个新的阶段，为我国木材科学在国际同学科前沿领域争得了一席之地，在我国人工林的建设与林业可持续发展中发挥了积极作用。

1997 年 1 月于北京

FOREWORD

As an important part of national economy, forestry belongs not only to basic industry, but also to public welfare, bearing duplicate task of environmental amelioration and development acceleration. In other words, forest, as the main body of land ecosystem, is one of the indispensable natural resources in human development. It plays an important role in ecological environment improvement, in maintenance of ecological balance and in realization of sustainable development.

Forest resource is deficient in China and not well-distributed with poor quality. The per capita average forested land, forest stock volume and amount of wood consumption in China account for only 17. 2%, 12% and 17. 6% of that of the world respectively. Nowadays, the existent natural resource of timber forest is on verge of exhaustion. With the development of national economy, with the increasing population and the improvement of people's living standard, the demand for wood is every increasing, and reaches 0. 25 billion cubic meters annually with an supply deficit of 50 million cubic meters, which makes up 20 percent of annual demand and severely hinders the economic construction. On the other hand, timber products of China undergo less proficient and deepened processing, and the utilization rate of wood in China is only 40 percent, which is lower than that of 80 percent in developed country. Serious waste of wood resources further accelerates the contradiction between demand and supply. The environmental problems facing China of soil erosion, desertification, shortage of wafer resources and decrease of biological species, and the frequent disaster of flood, drought and wind calamity have a close relationship with the above problems.

Planting trees to make the country green, to enlarge the resources of forest and to ameliorate the ecological environment is a basic policy of China. Sustainable forest development has been listed a strategic goal of long term development in the CHINA 21 CENTURY A-GENDA FORESTRY ACTION PLAN by the government after the UNEDC in 1992. A series of significant actions have been adopted to promote lots of projects such as forest ecological engineering, forest breeding, protection and utilization, combating against desertification, biodiversity protection, mountainous area development and local people's breaking away from poverty, as well as forest industrial exploitation, and remarkable achievements have been made. China forest resources such as forest coverage and forest stock volume are increasing steadily, especially in recent years. The preserved area of man-made fast growing forest land has reached 34. 25 million hectare, with an unprecedented favorable situation. Both its scale and speed are in the first place in the world. However striking problems be-

tween quality and quantity, supply and demand, management and benefit still exists. View-ing the situation from the whole, China is still confronted with the long term hard task of strategic targets to establish a quite perfect forest ecosystem and a quite developed industrial system. A lot of work need to be done to construct the 2 forest system. It should be indicat-ed that the research into relationship between forest cultivation and wood properties has been neglected in setting up of fast growing forest since 1960's. The man-made forest has not been directionally cultivated according to timber final usage. Therefore, the built fast grow-ing forests can not fit the demands of market. Moreover, the output of these forests have not been scientifically and reasonably utilized according to their properties, without a considera-tion of the relationship between utilization and timber properties, which leads to the condi-tion that the output of the forest is difficult to play their proper roles.

Wood science is the evidence of the improvement of technology of forest management and tree breeding, as well as presupposition of improvement of wood utilization technology. Meanwhile, it is the foundation of fast growing forest management and utilization. Domestic and overseas practice of forest management and tree breeding, as well as wood utilization shows that only if the wood science is taken as a foundation, it is possible to realize oriented cultivation and efficient utilization of wood. With the structural change of forest resources, the utilization of natural forest will be gradually replaced by fast growing forest. This is a new challenge to the wood science, which means a demand for wood science to provide effec-tive and scientific guide to manage and utilize the fast growing forest. It is a mission of wood science in a new era.

The book WOOD PROPERTIES OF MAIN TREE SPECIES FROM PLANTATION IN CHINA was written under the requirement of this new era's mission. It is complied by 50 wood scientists from 7 research institutes and universities with 5 years (1991 to 1995) hard-working. It is a wide covered and in-depth book that systematically deals with the properties of fast growing forest of many species from many provinces in China. It is also a symposium on fast growing wood properties that deals with the relationship between wood Properties and oriented cultivation, and between wood Properties and effecient utilization. Not only can it provide a scientific evidence for fine tree species breeding, intensive management and ori-ented cultivation of fast growing forest, but also a scientific guidance for scientific process-ing, optimization of technology and efficient utilization of man-made forest wood. The pub-lishing of the book indicates that wood science research in China has entered a new stage and gained a position in the field of world wood science. It will play an active role in the con-struction of fast growing forest and sustainable forest development in China.

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January 1997

　　木材是当今世界四大材料（钢铁、水泥、塑料、木材）中唯一可以再生的生物木质材料，是国计民生不可缺少的必需品。我国是个少林国家，木材资源不足。随着经济建设的发展和人民生活水平的提高，对木材的需要与日俱增，木材供不应求状况长期居高不下，严重影响国民经济的发展和人民生活的提高。

　　木材科学，是以认识木材自然现象、探索木材自然规律为内容，应用现代生物学、物理学、化学和力学的原理和技术，来研究木材解剖学特性、生物学特性、化学特性、物理学特性和力学特性，以及这些特性与树木遗传育种、生长环境、营林措施之间，与木材加工利用之间的关系的原理和规律，为林木的定向培育、集约栽培、优质高产，以及木材的科学加工、高效利用等，提供理论指导和科学依据的面向国民经济建设的一门应用基础科学。

　　木材科学，是营林培育科学技术进步的依据，是木材加工利用科学技术发展的基础。通过木材科学结合林木选育和栽培进行研究，研究木材材性与营林培育的关系，了解它们之间内在联系的规律，借以研究最佳林木选育措施和最优栽培新技术，实现林木定向培育和集约栽培，达到林木高产、优质，不但能够培育出生长快、干形好、抗性强的林木，满足社会发展和人民生活对木材日益增长的需求，而且能够培育出材质优、材性好，甚至具有某一特定材性指标的林木，达到国民经济各部门对木材越来越高的质的要求。通过木材科学结合木材加工和利用进行研究，研究木材材性与加工利用的关系，可以获知木材各种特性对木材加工利用的影响原理，找到与木材加工利用的关系规律，为研究最优木材加工工艺和最佳木材利用新技术，实现木材科学加工和高效利用，提高加工生产率，改进产品质量、延长使用寿命，增加产品种类，做到适材适用、材尽其用、小材大用、劣材优用，使有限的木材资源得到充分、合理、高效的利用。

　　世界上发达国家历来重视基础研究，视基础研究是人类利用和改善自然提供必要的知识基础，是新技术、新发明的先导和源泉。当代木材科学基础研究，近 20 年来取得了重要的进展。目前全球工业用木材资源已逐渐从天然林转向人工林，因此人工林木材材性研究在世界各国均引人注目，并作为大量投入的新研究领域。木材材性与营林培育、加工利用关系的研究已成为当今世界木材科学领域的一个热点或前沿。我国木材科学研究在 90 年代以前侧重于天然林木材材性研究，取得了巨大成就。自 60 年代以来，为缓解木材

供求矛盾,保障经济建设的木材供给营造了大面积人工林,这本可以大大缓解我国木材供求矛盾,向国家建设提供急需的木材。但是由于当初营造人工林时没有注重研究木材材性与培育的关系,未能按照用材部门对木材材性的要求营造人工林,以致现在已成林的人工林木材出现了难以适应市场需求的问题;对其产出的人工林木材又没有注重研究木材材性与加工利用的关系,以致其加工利用缺乏科学依据,产生种种问题和困难,严重影响了人工林木材的充分合理利用。至此,对人工林木材材性的研究才逐渐引起重视,国家在"八五"(1991～1995年)期间首次以《短周期工业用材林木材性质研究》课题列入国家科技攻关计划,作为国家重点关键课题开展系统科学研究。

　　本项研究由中国林业科学研究院主持,由南京林业大学、北京林业大学、东北林业大学、中南林学院、安徽农业大学和华中农业大学,共7个单位的木材学专家在统一科研计划下共同完成的。5年来(1991～1995年)共完成了从辽宁、吉林、黑龙江、内蒙古、云南、贵州、四川、广东、广西、湖南、湖北、江西、福建、江苏、浙江、安徽、山东等省(区)采集的杉木、马尾松、云南松、湿地松、火炬松、日本落叶松、长白落叶松、中林三北1号杨、柠檬桉、兰考泡桐等10种人工林木材和杉木、马尾松、长白落叶松、云南松等4种天然林木材的幼龄材与成熟材及人工林与天然林木材解剖性质、化学性质、物理性质和力学性质的研究;不同遗传结构人工林木材包括杉木76个种源、火炬松31个种源、美洲黑杨6个无性系、白桦5个种群等118个品系木材性质变异规律的研究;不同栽培措施包括间伐强度、施肥处理、土壤类型、种植密度和立地条件对杉木、马尾松、湿地松、火炬松、日本落叶松、尾叶桉、北京杨、毛白杨、I-69杨、昭林6号杨、赤峰36号杨等11种人工林木材性质影响规律的研究;以及杉木、马尾松、云南松、湿地松、火炬松、长白落叶松等5种人工林木材性质早期预测的研究。

　　本项研究涉及的内容包括41个测试项目:木材解剖方面的有纤维长度和宽度、胞壁厚度、胞壁率、胞腔直径、生长轮细胞个数、组织比量、微纤丝角、超微结构;木材化学方面的有综纤维素、α-纤维素、多戊糖、木质素、1%NaOH抽出物、苯醇抽出物、冷水抽出物、热水抽出物、pH值、酸缓冲容量、碱缓冲容量、矿质元素、相对结晶度、糖基比、差热分析、热重分析;木材物理、力学方面的有晚材率、年轮宽、生材含水率、吸水性、干缩性、木材密度、渗透性、扩散性、热性质、顺纹抗压强度、抗弯强度、抗弯弹性模量、顺纹抗拉强度、顺纹抗剪强度、冲击韧性和抗劈力等。

　　通过完成以上研究,获得了丰硕的成果,从木材解剖、化学、物理、力学各方面全面揭示了我国人工林木材材性特点及其幼龄材与成熟材的材性差异规律和部分树种的天然林与人工林木材材性差异规律;从种源、种群、无性系各层次上揭示了人工林主要树种在不同遗传结构层次上的材性变异规律;从不同立地条件、种植密度、间伐强度、施肥方法、土壤类型等方面揭示了栽培措施对人工林主要树种木材材性影响规律;从木材株内自身生长发育阶段的材性变化规律提出了人工林主要树种木材材性早期预测方法;从木材物

理力学和化学性质出发，探讨了人工林树种木材材性对制浆和制胶合板的适应性及其优化工艺条件。

本研究专著是根据以上获得的研究结果，由前述进行该项研究的 7 个科研单位和高等院校的木材学专家（详见著者名单）著述而成。该专著共分 8 章，第一章为中国主要人工林树种木材解剖性质与超微构造，第二章为中国主要人工林树种木材化学组成与化学性质，第三章为中国主要人工林树种木材力学性质，第四章为中国主要人工林树种木材物理性质，第五章为不同种源、种群、无性系木材性质，第六章为不同培育措施对人工林木材性质的影响，第七章为人工林木材生长过程中材性变异规律与早期预测，第八章为人工林木材材性对制浆与制胶合板的影响。

本专著是对我国主要人工林木材材性进行了多树种、多地域、多领域、多内容的全方位研究所取得的丰硕研究成果的系统论述，是一部与人工林林木定向培育和木材高效利用紧密结合的木材材性方面基础研究专著。它一方面可为工业人工林林木定向培育、集约栽培提供科学依据，另一方面可为工业人工林木材科学加工、高效利用提供理论指导。

为使本研究专著的著述工作顺利完成，设有主编和编委会，负责日常组织著述工作。编委会由各章统稿人姜笑梅和柴修武（第一章）、陆熙娴和黄洛华（第二章）、骆秀琴（第三章）、鲍甫成（第四章）、费本华和刘盛全（第五章）、方文彬和张立非及黄洛华（第六章）、王金满和秦特夫（第七章）、王金林和李忠正及李春生（第八章）组成。主编为该课题负责人鲍甫成、江泽慧，负责本专著的设计与统稿。

本研究专著限于著者水平，不妥甚至错误之处在所难免，恳请各方不吝指正。

鲍甫成　江泽慧

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Wood, being the only re-productive one of 4 major sorts of row material (steel, cement, plastic and wood) in the world, is an indispensable kind of necessities in national economy and people's living. In a country with a small coverage of forest and a lackage of wood, the contradiction between ever-increasing wood demand and deficient supply becomes more and more serious with development of economical production and improvement of people's living. As a result, it greatly influences the national economic development and people's living.

Wood science takes the recognition of wood nature phenomenon and exploration of the wood nature regularity as its contents, deals with the subjects of wood anatomy, wood biology, wood chemistry, wood physics and wood mechanics, and the relationship between these subjects and forest genetics and tree breeding, forest environment, silvicultural measures and wood processing and utilization by means of applying the principles and techniques of modern biology, physics, chemistry and mechanics. It provides theoretical guide and scientific evidence for tree breeding and cultivation, reasonable wood utilization, relates to both forest management and forest industry and permeates in the whole course from tree breeding, wood processing to wood utilization.

Wood science is the foundation of development of forestry and the presupposition of improvement of the technology of wood processing and utilization. Studying the relationship between wood properties, forest management and tree breeding through the wood science, tree breeding and cultivation will help people to know the inherent relation between them, and to determine the most efficient methods of tree breeding and cultivation so as to complete the tasks of oriented cultivation and intensive cultivation and to have a high forest outputs with good properties. As a result, not only the man-made plantation with good-shaped-trunk and anti-diseases can be cultivated in order to meet the ever-increasing demands of social development and peoples living, but also the wood with good properties and even with the specific properties can be cultivated in order to meet demands for high quality wood from various departments in the economical construction. Studying the relationship between wood properties and utilization through the wood science, wood processing and utilization will help people to know the effects of specific wood properties on the wood processing and utilization, so as to determine the best wood processing techniques, the most efficient utilization methods and to improve the manufacture benefits and the quality of the products, to elongate the lives of the products, and to enhance the types of the products. That means reasonable, optimal utilization of the limited forest resources.

The developed countries always place emphasis on the basic science, and considered it the important and basic knowledge, the guide and the source of new techniques and inventions to utilize the nature. A great progress has been made on wood sciences, one of the basic science, in the past 20 years all over the world. The place of natural forests are gradually being taken by the man-made plantation for the industrial consumption. Therefore, research on the properties of wood from the man-made plantation has become a new research area being paid appreciable attention and finances by most countries. The research on the relationships between wood properties, forest management, wood processing and utilization is becoming a hot topic and a new forward position in the field of wood science in the world. Before 1990's, wood science researches in China had been placed emphasis on the wood properties of natural forest and had made abundant achievements. From 1960's, large area of man-made plantation had been cultivated and that was supposed to supply urgently-needed wood in the nation's economic construction and to balance the demands and supplies. However, the man-made plantation now can not fit the demands of market because no research work on the relationship between wood properties and forest management had been conducted before cultivation and the man-made plantation had not been cultivated according to the demands of the wood consuming department. The outputs of the man-made plantation have not been studied on the relationship of wood properties and its utilization. Consequently, there is a shortage of scientific evidence for their utilization and many difficulties and problems appeared, this greatly influences the reasonable utilization of wood. Because of this, attention of the research on the properties of fast growing wood is gradually paying, and the STUDIES ON THE PROPERTIES OF WOOD FROM PLANTATION was listed in the Eighth five-year plan (1991-1995) of national key technologies R&D program, now the proposed achievements have been made.

The project was managed by Chinese Academy of Forestry and was completed according to the plan by means of cooperation of wood science experts from 7 research instiues and universities, including Nanjing Forestry Univ., Beijing Forestry Univ., the Northeastern Forestry Univ., the Middle Southern Forestry College, Anhui Agriculture Univ. and the Middle China Agriculture Univ.. During the five years(from 1991 to 1995), the anatomy features, Chemical properties, physical and mechanical properties of 10 species of man-made plantation such as Common China-Fir (*Cunninghamia lanceolata*), Masson Pine (*Pinus massoniana*), Yunnan Pine (*Pinus Yunnanensis*), Slash Pine (*Pinus elliottii*), Loblolly Pine(*Pinus taeda*),Japanese Larch (*Larix kaempferi*), Korean Larch (*Larix olgensis*), Poplar Sanbei No. 1 (*Populus nigra* × *P. simonii* cv. 'Zhonglin Sanbei-1'), Lemon Eucalyptus (*Eucalyptus citriodora*), Paulownia Lankao (*Paulownia elongatia*) from 18 provinces, including Liaoning, Jilin, Heilongjiang, the Inner Mongolia, Yunnan, Guizhou, Sichuan, Guangdong, Guangxi, Hunan, Hubei, Jiangxi, Fujian, Jiangsu, Zhejiang, Anhui, Shanxi and Shandong, were studied. The property variations of totally 118 varieties including Common China-Fir of 76 provenances, Loblolly Pine of 31 provenances, Cotton Wood (*Populus del-*

toides) of 6 clones and Asian Birch (*Betula platyphylla*) of 5 population were studied. The effects of silvicultrural practices such as different thinning, fertilization, planting density, soil type and site condition on the properties of fast growing wood were studied through 11 species including Commom China-Fir, Masson Pine ,Slash Pine, Loblolly Pine ,Japanese Larch, Timor Mountain Gum (*Eucalyptus urophylla*), Poplar Pikinica (*Populus × beijingensis*), Chinese White Poplar (*Populus tomentosa*), Poplar 1 -69 [*Populus deltoides* cv. '*Lux*' (*I*-69/55)], Poplar Zaolin No. 6 (*Populus ×xiaozhuanica* cv. '*Zhaolin*-6'), Poplar Chifeng 36 (*Populus × xiaozhuanica* cv. '*Chifeng*-36'). Meanwhile, the wood properties forecast of 5 fast growing trees such as Commom China-Fir, Masson Pine, Slash Pine, Loblolly Pine and Korean Larch were studied. Wood anatomy features include tracheid (fiber) length and diameter, cell wall thickness, cell wall ratio, diameter of lumen, number of cells in the same ring, tissue proportion, micro fibrillar angle and ultra structure; Wood Chemical features include holocellulose, α-cellulose, pentosan, lignin, 1%NaOH extract, benzene-alcohol extract, cold water extract, hot water extract, pH value, acidic buffer content, base buffer content, mineral, relative crystallinity, ratio of sugar units, differential thermal analysis, thermo-gravimetric analysis; Physical and mechanical properties include percentage of latewood, ring width, moisture contents of green wood, water-absorbing capacity, shrinkage, density, fluid permeability and diffusion, thermal properties, compressive strength parallel-to-grain, bending strength, elastic modulus of bending strength, tensile strength parallel-to-grain, shearing strength parallel-to-grain, toughness value and cleavage resistance, etc.

Through these studies, wood properties characters of the main fast growing trees species in China, the variation of juvenile and mature wood of the major species, and the differences between natural forest and plantations of partial species were revealed from the aspects of wood anatomy, wood chemistry, wood physics and wood mechanics; The fast growing wood properties variations were revealed from the aspects of provenances, populations and clones; The effects of different silvicultrural practices such as sorts of site condition, planting density, soil type , thinning and fertilization on wood properties of the major species of fast growing wood were also revealed; The wood properties forecasting method of main fast growing trees were provided according to the principles of different properties in different growing period within a tree. Mean while, from the point of physical and mechanical properties, the adaptability to made pulp and plywood with the man-made plantation were explored.

The monograph was compiled by the experts in wood science from 7 research institutes and universities (details see the list of the authors) according to the research results mentioned above . It is divided into 8 chapters respectively. In which, the first chapter is about anatomy features of man-made plantation, including the ultrastructure features, the second is chemical properties, the third is physical properties, the fourth is mechanical properties, the fifth is wood properties variation of different provenances. populations and clones, the