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RESEARCH PROGRESS OF SOLID WOOD BENDING SOFTENING TECHNOLOGY. REVIEW

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ABSTRACT

The softening process of wood bending has a very important influence on the performance, forming shape, and yield of bentwood. The paper reviewed the typical softening processes in solid wood bending by analyzing the various softening mechanism and softening processes. The main influencing factors of the softening technology on the bending properties were summarized based on the comparative analysis of the related research progress of wood softening. In view of the lack of systematic analyses of the cost and environmental factors associated with the softening process, this paper goes in detail analyzing the major softening technologies with comprehensive comparison of the economic and environmental advantages and disadvantages. The paper also draws light on the development trends of softening technology that can be implemented in wood industry which can hence improve the added value of wood. Under the background of green development, the authors believe that the softening technology should not only benefit the economic efficiency but also meet the social needs of low-carbon and environment-friendly.

KEYWORDS: Softening process, solid wood bending, bending performance, environmental protection.

INTRODUCTION

Wood is one of the natural materials widely used in furniture making and is easy to develop and utilize. According to the characteristics of the wood, the wood can be softened (plastification) before bending, and then the wood can be bent and then dried, and shaped. In the bending process, various softening methods have been developed and accumulated. Reasonable use of different softening processes can effectively improve the plasticity of wood and reduce its rigidity, which is beneficial to actual production and processing.

Traditional curved wood parts such as backrests and armrests are usually spliced together by several curved pieces. For example, the round armchair in the Chinese Ming Dynasty was simple, light in body, smooth in bars, and used similar curved wood technology. However, the procedure of this production method is relatively complicated and time-consumed with high wood loss. As technology advanced, wood softening was applied to improve the bending efficiency of timber (Jiang et al. 2008). This technology can effectively solve the above problems, but the issues of low wood bending success rate, small curvature radius, and difficulty in realizing multi-dimensional bending have not been well solved (Cao 2006). This has also become a barrier to the development of bentwood products (Esteves and Pereira 2009).

In the middle of the 19th century, Michael Sonnett, based on wood bending technology, began to use solid wood for softening processes such as boiling and steaming, then bending and fixing, and has launched the Sessel series of 14 sets of bentwood chairs, creating a modern precedent of solid wood bending technology. In the 1990s, Denmark made a breakthrough and proposed the compression bending technology of solid wood along the grain. This type of technology is a technology that compresses the wood in the longitudinal direction after the wood is softened and then bends in a multi-dimensional direction to obtain a small bending radius of curvature. Song et al. (2004) and Song and Li (2009) studied the multi-dimensional bending technology of wood along the grain. Compared with the traditional wood bending component manufacturing technology, this technology can well solve the problems of the conventional manufacturing techniques, such as the need to bend while hot, the bending radius of curvature is significant, and it is not suitable for multi-dimensional bending (Wang and Xu 2014). After the wood is bent, the best parts should be dried and shaped. The moisture content and drying temperature are the key factors to reducing the spring back and improving its stability (Li et al. 2000, Song and Li 2007, Arnold 2010, Kocaefe et al. 2015, van Blokland et al. 2020).

In recent years, with the rapid development of bending technology, the scope of research has been expanding, which mainly includes the following areas: *1)* The influence of the wood softening process on the performance of bentwood (Liu and Shen 1990, Li 1998a,b, Tong et al. 2011, Wang et al. 2019a,b, Yang et al. 2019, Shen et al. 2020); *2)* Optimal bending process conditions for specific wood (Ye and Liu 2004, Ye and Wu 2005, Tong et al. 2011); *3)* to improve the softening effect of wood to achieve the best bending performance (Li 1998, Tong et al. 2011, Li et al. 2014, Wang et al. 2019); *4)* According to relevant criteria such as minimum bending radius and elastic modulus, the wood with excellent bending performance is screened (Chen et al. 2000, Shen et al. 2020).

The development of wood bending technology has added richer furniture forms to the furniture industry. Whether inheriting the classics or pursuing innovation, bentwood furniture has already occupied a place in the home environment. Even though the production process of bentwood furniture is more complicated than that of ordinary furniture, relying on its characteristics and classic design, a large number of international home furnishing brands with bentwood furniture as representative products have emerged, such as KnoII (http://www.knoll.com), Muuto(https://professionals.muuto.com), Norr11(https://norr11.com/), Northern(https://northern.no/), Nwlh(https://nwlh.jp/), Thonet(http://www.thonet.de), Twentytwentyone (https://www.twentytwentyone.com/), Vitra(https://www.vitra.com/),

Puretimber(http://www.puretimber.com).

The solid wood softening technology effectively improves the use-value of wood, conforms to the concept of green design, and can also maximize the use of low-quality materials, reducing the loss of precious wood resources. More importantly, the appearance of the furniture made of bentwood is brisk and soft, and the lines are smooth and changeable. Therefore, it is essential to study the softening mechanism of wood for solid wood bending technology. Based on this, the author discusses the basic principle of softening technology in wood bending, the classification of wood softening technology, and related experimental research progress.

The typical process of solid wood bending

The method of solid wood bending mainly adopts manual and mechanical forms, which can be divided into single and multi-dimensional bending. The cross-section remains unchanged after single-dimensional bending, while multi-dimensional bending is wood bending while being compressed. The shape of the bending can be two-dimensional space such as L, U, etc., or a three-dimensional space curve such as the back leg parts of a chair. It uses molds, steel belts, end blocks, etc., to press and bend the softened wood into the required shape. The primary process of solid wood bending is shown in (Fig. 1).

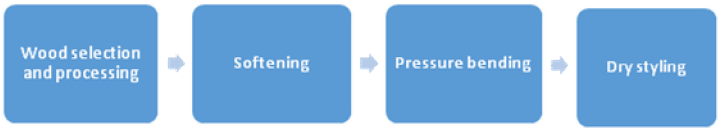

Fig. 1: Flow chart of solid wood bending.

To improve the quality and yield of the bent parts, a lot of preparation work must be done before bending. Because the structure and types of wood are complex and diverse the bending properties will also be very different, and a lot of research and experiments have been done on this (Ozarska and Daian 2010, Kuljich et al. 2015, Shen et al. 2020). In selecting wood materials, in addition to screening the wood surface, it is also necessary to determine the moisture content of the selected materials to meet the specific softening process (Studhalter et al. 2009). The properties of wood are improved through various wood softening processes so that the wood has temporary plasticity before bending so that the wood can be bent as required under the action of force. After softening treatment, the temperature of the wood should be avoided to reduce the plasticity and affect the bending effect of the wood. Therefore, before bending, the sample iron block can be heated in a muffle furnace before use or bent simultaneously during the heating process (Chen et al. 2000, Ye and Liu 2004). After bending, due to the characteristics of wood, it must be dried and shaped to reduce its moisture content to about 10% to achieve shape stability (Song and Li 2007).

The main influencing factors of solid wood bending

The success rate of solid wood bending is affected by many aspects, which can be divided into two parts according to the implementation steps. The first part is before bending: *1)* the softening process; *2)* the type of wood; *3)* the direction of growth rings, cross-sectional dimensions, and moisture content of the wood; *4)* the defects and surface roughness of the wood. The second part is during the bending process: *1)* softening temperature and softening time; *2)* longitudinal compression rate and bending speed of the test material (Li 1998, Song et al. 2002, Rice and Lucas 2003, Song et al. 2004, Ye and Wu 2005, Boonstra et al. 2007, Nocetti et al. 2015, Boruvka et al. 2018, Hein and Brancheriau 2018, Cheng et al. 2021). In addition, Burvill et al. (2013) found a correlation between end force and bending properties, demonstrated the effect of end force on the bending properties of wood, developed a differential end force sensor (DEFS), and successfully tested the sensor in subsequent experiments, features and performance (Burvill et al. 2015, 2016). This differential end force approach may improve the performance of the wood bending process, especially in semi-automated production environments where excessive-end compression forces can cause damage to the bentwood components, resulting in associated production delays and material waste.

Principles of wood softening

Wood is a natural composite material composed mainly of cellulose, hemicellulose, and lignin (Hill 2007, Wang et al. 2017). The proportion is 40% to 50%, 15% to 25%, 20% to 40%, of which the most significant proportion is the cellulose of wood. Cellulose is divided into two parts: the crystalline region and the non-crystalline region, both of which are molecular chains linked by glucose groups in the form of pyran rings, only the relationship of molecular chains is different (Boonstra and Tjeerdsma 2006). The nature of the crystallization zone determines that the softening temperature of cellulose is much higher than the range of wood bending softening temperature, and the water content has almost no effect on the glass transition temperature, so the wood softening effect is not affected by the crystallization zone (Bhuiyan and Hirai 2005). At the same time, the softening temperature of cellulose and lignin decreased significantly with the increased water content (Xu et al. 2020). From the molecular structure of wood components, the amorphous region of cellulose, hemicellulose, and lignin has a strong affinity for water. It plays a significant role in the hygroscopic expansion of the wood. The softening point of lignin is closely related to the presence of moisture, and the content and softening characteristics of lignin are the main factors affecting wood softening (Hughes et al. 2015).

Elastoplasticity of wood is affected by changes in moisture content and temperature (Furuta et al. 2001, Borrega and Kärenlampi 2010). Water is a polar molecule. When water enters the cell wall, it mainly interacts with the hydroxyl groups in the amorphous region of cellulose, thereby increasing the distance between molecules, that is, increasing the free volume, which provides the necessary conditions for the vigorous movement of molecules space (Li 1997). At the same time, the glass transition temperature is lowered. Suppose there is a lack of energy and molecules. In that case, even if there is an ample free volume space, it does not provide sufficient softening conditions for the wood, and only when energy and water act together as plasticizers the effect of wood softening can be better achieved (Li et al. 2000, Bekhta and Niemz 2003, Chen et al. 2018).

Huang et al. (2018) studied the bending properties of wood under different temperature conditions. They proved that in the state of water saturation, increasing the temperature can increase the plastic deformation of wood (Li et al. 2004). Since water cannot enter the crystalline area of cellulose, swelling does not occur, and the softening effect is not optimal (Li 1998). Ammonia is more polar than water and can enter the amorphous region of cellulose; and can also enter the crystalline part of cellulose and cause microfibrils to swell, increase molecular spacing, and achieve wood elastic plasticization (Zhang et al. 1994, He et al. 2021).

The key technologies of wood softening

Wood softening treatment can be divided into physical and chemical categories according to its properties be further subdivided into hydrothermal treatment, electromagnetic wave heating softening alkali treatment, ammonia treatment, etc. To improve production efficiency and the wood softening effect, the current softening process mainly adopts the combination form improve to soften the wood.

Physical softening treatment

Physical softening uses the effect of temperature and moisture to achieve the purpose of softening, which can be divided into processes such as boiling, steaming, and electromagnetic waves. Their mechanism of action is the same, but the form of heat transfer is different. The heat transfer of boiling and steaming is gradually heated by the wood surface to soften the wood core layer and then bend it into the desired shape. This technology is safe and convenient, the equipment is simple and easy to use, it can be made by yourself, and the medium used is non-polluting. It has become a commonly used wood softening technology and has been widely used in production. Electromagnetic wave heat is generated simultaneously inside and on the wood section, so it can quickly and evenly transfer heat to the wood inside and outside. The size of the energy can be well controlled during the heating process so that the wood moisture content gradient is more consistent (Obataya and Tomita 2002, Boonstra et al. 2007). Based on these advantages, microwave technology has become a new technology in the field of wood softening. For microwave treatment, the effect of its mechanism on the temperature change of wood during treatment and the change of wood properties after treatment were mainly studied (Hein and Brancheriau 2018, Xu et al. 2020, Mascarenhas et al. 2021).

Hydrothermal softening

Water has a vital role in the softening treatment, as it acts as a plasticizer to expand the volume of wood, especially when the water content reaches the fiber saturation point of wood, the volume expansion reaches its maximum, and is also the best condition for wood bending (Song et al. 2002, Endo et al. 2016). Under the action of heat, the energy of lignin, cellulose, and hemicellulose molecules in the non-crystalline region can be increased, and combined with the activity of moisture, the non-crystalline region of cellulose swells wet, lignin is in the viscous flow state, hemicellulose loses its linkage, and wood plasticity increases (Song et al. 2004). For the hydrothermal softening treatment, the bending mechanical properties of wood and the deformation mechanism are mainly studied, and the main effects of moisture content and

temperature on wood bending are analyzed.

Moisture content is an essential parameter in the wood softening process. To achieve the best bending properties and improve the plasticization of cellulose and hemicellulose, the researchers carried out a series of studies according to the moisture content of the wood (Esteves et al. 2007, Arnold 2010, Endo et al. 2016, Cheng et al. 2021). If the moisture content of the wood after softening treatment should be close to the fiber saturation point, i.e., about 30% is the best wood moisture content (Song et al. 2002). If the moisture content is too high, it is easy to generate excessive static pressure and damage the cell wall of the specimen (Li 1998). Moisture content not only affects the bending properties of the wood but also affects the drying and fixing of the parts after bending (Dong et al. 2008). After the wood is bent, the shrinkage of the cells will occur. If the cell wall is not damaged, the moist heat treatment can restore the shrinkage of cells (Zhao 2021). Yang et al. (2019) bent poplar wood by steam molding to control the occurrence and extension of acceptable view damage during wood bending, studied the damage mechanism of wood bending defects, analyzed the viscous buckling and fracture of poplar wood cell wall microstructure, providing a theoretical basis for the bending wood process, and providing a basis for the rational use of wood.

The main components of wood cell walls are cellulose, hemicellulose, and lignin, and the softening temperature is determined by the glass transition temperature of the wood components. In the dry state, the glass transition temperatures of hemicellulose and lignin were 167-217°C and 134-235°C, respectively, while in the wet state, their temperatures dropped to 54-142°C and 77-128°C, respectively. It changes from a glassy state to a highly elastic state, promoting increased wood plasticity (Ye and Liu 2004). Hemicellulose is the first structural compound to be affected by heat, even at low temperatures. Since water molecules cannot swell the crystalline region of cellulose, it has little effect on the transition temperature of cellulose. The temperature has a significant impact on the flexural properties of wood. The increase in temperature weakens the strength of the wood, which is conducive to the bending of the wood (Gao et al. 2014), However, when the temperature is too high, it will increase the cost of investment, and it will also cause irreversible changes to the properties of the wood, reducing the physical properties of the wood (Song et al. 2002, Bekhta and Niemz 2003, As et al. 2018).

Electromagnetic wave heating and softening

Electromagnetic wave heating is the internal heating of objects, which can be divided into the microwave and high-frequency heating (Zielonka and Gierlik 1999). In the heating process, it is necessary to place the wood as the object to be heated (dielectric) in a high frequency or microwave electric field, the dipoles with positive and negative polarities in the dielectric, such as moisture or adhesives inside will align in the direction of the electric field. Under the action of millions of polar changes per second in the electric field, the dipoles move violently, and the molecules inside the object rub to generate heat. The principle of high-frequency heating is the same as that of microwave; the difference lies in the use frequency and processing method of the two (Huang et al. 2007).

Microwave technology is mainly used in the field of wood bending in the following aspects: *1)* To make the moisture content of wood suitable for microwave treatment, which can be

softened by independent heating, combined with hydrothermal treatment, or treated with auxiliary heating of wood. The optimum process parameters for microwave softening were established (Studhalter et al. 2009, Burvill et al. 2013, de Peres et al. 2016). The application of microwave technology in the wood heating field can improve wood's compression rate with the grain and reduce the radius of curvature of bending (Song and Li 2009, Wang et al. 2019); *2)* The softening degree of the wood is controlled by adjusting the technological parameters of the microwave, and the wood is bent synchronously during microwave irradiation and then dried by microwave after bending (Xu et al. 2020); *3)* Drying and shaping softened and bentwood using microwave heating (Xu et al. 2020). The softening effect of microwave heating is obvious in the case of water-saturated materials (Chen et al. 2000, Gasparik and Gaff 2013). Therefore, the wood moisture content is the main factor affecting microwave heating efficiency, and it is also an important research direction at present (Studhalter et al. 2009). In addition, heating power and time also play an important role in product quality (Li 1998, van Blokland et al. 2019). The relationship between microwave treatment time, microwave power, wood moisture content, and the wood softening effect was investigated in the microwave softening process and used the response surface method to optimize the microwave-assisted softening process by Yao et al. (2014).

The main features of high-frequency dielectric heating technology are fast, uniform, and selective heating, so the range of use is constantly expanding. In the field of bentwood technology, the application of high-frequency technology can greatly reduce the production cycle and significantly improve production efficiency. However, high-frequency heating technology is more complex for the operation, especially the control of softening time is strictly required; otherwise it is difficult to ensure the softening quality (Wu 1994). Liu and Shen (1990) took the Cudrania and Chinese ash as test materials and made an experimental analysis on the main influencing factors such as high-frequency heating power density and wood moisture content. And the softening speed and softening quality of wood under high-frequency heating were measured, and its efficiency was increased by nearly 12 times compared with cooking softening.

Chemical softening treatment

The chemical softening treatment uses inorganic chemicals to soak and impregnate the wood so that the cellulose crystal area of the wood swells in the dilute acid and dilute alkali solution, which cannot be achieved by water (Xue and Zhao 2007). Chemicals have a more comprehensive effect on wood structure, causing wetting and swelling of the crystalline regions of cellulose, and affecting the non-crystalline regions of cellulose, hemicellulose, and lignin to varying degrees. Therefore, after treatment with chemicals, the softening effect of wood will be further improved (Zhang et al. 1994, Li 1998, Korkut 2008, Wang et al. 2019).

The chemical softening treatment of wood mainly uses chemical reagents such as liquid ammonia, ammonia water, ammonia gas, urea, and lye to soften the wood. Among them, ammonia-based chemical softening and lye softening are more widely used. Li Jun et al. (1998) softened wood by ammonia water treatment and microwave heating, improving production efficiency and determining the best process conditions (Li 1998). Compared with hydrothermal softening, ammonia softening can significantly degrade lignin, cellulose, and hemicellulose, and

at the same time, it can reduce the content of extractives in wood (Jiang and Ma 2016). And the crystalline area of cellulose is also affected by ammonia, so ammonia reacts with cellulose to form ammoniated cellulose, which can damage the crystalline area of cellulose and expand the distance between celluloses at the same time. More importantly, ammonia water can distort the lignin and soften the wood (Yamashita et al. 2018, Shen et al. 2020a,b). The mechanical properties of water-treated samples, ammonia-treated samples and samples treated with ammonia-recombined lye were compared, and it was determined that the radius of the samples softened by ammonia-recombined lye was smaller, and the damage was more minor.

The solubility of cellulose in alkaline solution is excellent, and this process is called mercerization. Under the action of an alkaline solution, OH can make cellulose swell first and then dissolve, and the crystal form changes at the same time (Xu et al. 2020). Cellulose swells, causing hydrogen bonds between cellulose molecular chains and other structures such as lignin and hemicellulose to break and separate (Wang and Liu 2016). However, cellulose is relatively stable under the condition of low alkali concentration, and the lye mainly acts on other components other than wood cellulose (Chen et al. 2018). The effect of alkali treatment on the non-crystalline area of the wood cell wall is dominant, which can dissolve and extract the extractives in the non-crystalline area, make the arrangement of microfibrils orderly, and form a firmer bond (Xue and Zhao 2007). Japanese scholar Ishikura Yukiko studied the effect of alkali treatment on longitudinal shrinkage, bending properties, and cellulose structure (Ishikura et al. 2010). In addition, Zhang Lina's research group from Wuhan University has developed NaOH/Urea cellulose solvent, which can dissolve cellulose in all components and be used to prepare various regenerated cellulose materials and high-value-added cellulose composite materials. And it can solve the problem of environmental pollution caused by a large amount of lye, but the temperature required in the dissolution process is relatively low, and it has not been industrialized at present (Xue and Zhao 2007).

Combined softening treatment technology

The development of softening technology has given more added value to wood, making it suitable for bending production. This process has many softening processes, adding more options for wood softening. But specific to one of the processes, its defects are apparent. For example, hydrothermal softening is challenging to transfer heat into the wood, and microwave softening requires high moisture content of the wood. Therefore, considering the complex structure of the wood itself and the diversity of objective factors, it is obvious that only using a specific process cannot meet the actual production needs.

To improve the softening effect of wood and make up for the shortcomings, researchers use two or more softening processes to treat the wood, trying to achieve the best softening effect. According to the research progress, the primary combination forms can be roughly divided into the following categories; hydrothermal and microwave combination (Song and Li 2009, Tong et al. 2011, Wang et al. 2019); ammonia and microwave combination (Li 1998); alkali and microwave combination (Xue and Zhao 2007); and urea combined with microwave. These combined forms greatly reduce the problems of high energy consumption and low softening efficiency caused by a single process.

The hydrothermal-microwave joint softening treatment enables the wood to swell the amorphous region of cellulose, hemicellulose, and lignin under the action of moist heat, providing free volume space for the vigorous movement of molecules. The glass transition temperature of lignin is reduced, and the temperature gradient inside the wood can be eliminated under microwave irradiation, the softening time is shortened, and the wood can quickly achieve a better softening effect (Studhalter et al. 2009, Torgovnikov and Vinden 2009, Gasparik and Gaff 2013, de Peres et al. 2016, Domeny et al. 2021). In addition to water as a pretreatment medium for wood, chemical media such as ammonia and urea can also be used as auxiliary softening means. Li Jun combined the advantages of each process and used the combined action of microwave and ammonia to soften solid wood, which achieved the expected purpose (Li 1998). Microwave treatment combined with chemically immersed wood results in better-bending properties and bending quality than conventional hydrothermally treated wood.

In the field of chemical softening of wood, ammonia is an ideal wood softener. This is because ammonia requires less of the species to be softened and has an almost unrestricted effect on the amorphous and crystalline zones of the wood cellulose, thus allowing for the desired softening impact. However, softening the wood with ammonia water often takes a lot of time, and the softening effect is not ideal. This is because the energy of molecular motion is not enough. The common method is to add ammonia liquid to water to boil or steam the wood to increase the softening of the wood. In addition, Li et al. (2014) studied the softening treatment of poplar veneer through supercritical ammonia. Using this method, the bending performance of the veneer of the specimen is better, and the softening time is greatly shortened; supercritical state, high process cost (Liu 2004).

RESULTS AND DISCUSSION

Comparative study on softening technology

In the wood softening process, hydrothermal treatment is a common treatment method in current production, which is mainly divided into two groups: steaming and boiling. Its advantages are simple equipment, safe operation, no environmental pollution, small investment, and suitable curved wood furniture production for small enterprises. However, this method causes uneven heating inside and outside the wood due to the poor thermal conductivity (Li et al. 2020). At the same time, for thicker specimens, the heating time is very long, and the efficiency is relatively low, resulting in an unsatisfactory softening effect. Wang et al. (2019) compared the softening treatment of plantation teak with water heat treatment and ammonia water. The analysis of the bending properties after treatment showed that the softening method of ammonia water treatment is better than hydrothermal treatment for plantation teak. The comprehensive effect of ammonia reagent treatment is the most ideal in the chemical reagent softening process. Ammonia plasticizing has lower energy consumption and shorter process time than traditional cooking (Pařil et al. 2014). However, due to the strict requirements for equipment in the softening process, the high engineering cost, and the high cost of softener preparation materials, among which NaOH, acetic acid, and other wastes have a great impact on the surrounding environment, they are not widely used in actual production. Softening wood

with chemicals and processes can achieve excellent softening results, but with today's increased environmental awareness, such modified products cannot easily gain market acceptance (Ali et al. 2021). In practice, microwave heating can better control the temperature and evenly distribute the heat inside the wood in a short time (Zielonka and Gierlik 1999). Here are some of the main advantages of the technology. Compared with traditional heat treatment methods, this technology saves a lot of energy, material, and time (Dong et al. 2008, Torgovnikov and Vinden 2010). The softening process factors are compared in Tab. 1.

Tab. 1: Comparison of typical softening processes.

Processing technology	Processing medium	Advantage	Disadvantage	Application	References
Boiled, steamed	liquid water or saturated vapor	Simple equipment and safe operation. No pollution to the environment, small investment.	Water does not affect the wood crystallization area, and the softening effect is not good. Uneven heating inside and outside the wood, long heating time, limited wood size. Low energy and low efficiency.	high-temperature modification of wood, wood softening	(Li 1997, Esteves et al. 2007, Huang et al. 2007, Korkut 2008, Kuljich et al. 2015, Xiao et al. 2018, Shen et al. 2020)
Chemical solvent	ammonia gas, ammonia water, liquid ammonia	Soften wood with lower moisture content. Easy to clean with little impact on the physical properties of wood.	The material cost of softener formulation is high, and the waste greatly impacts the surrounding environment. Softening is prone to discoloration of the wood. Ammonia processing time is long, and safety is poor.	wood modification, wood softening	(Li 1998, Weigl et al. 2011, Miklecic et al. 2012, Pařil et al. 2014, Wang et al. 2019, Samani et al. 2021)
Electromagnetic waves	polar dielectric	Heating has the advantages of fast speed, uniform heating, and little influence by the wood thickness. Easy temperature control for optimum processing conditions.	Equipment cost and high energy consumption. Equipment parameter requirements are complex The softening effect is affected by tree species, moisture content, etc.	wood drying, wood softening improving of fluid permeability	(Norimoto and Gril 1989, Zielonka and Gierlik 1999, Huang et al. 2007, Torgovnikov and Vinden 2010, Gasparik and Barcik 2014, Yao et al. 2014, Mascarenhas et al. 2021)

Development trends of softening technology

To improve the success rate and product quality of wood bending manufacturing, it is necessary to actively research more excellent softening technology. Based on the current situation of the existing softening process and softening methods, combined with the main

problems currently faced, the future technological development will show the following two development trends.

The trend of going green

With the development of the times, environmental issues have become a factor that must be considered nowadays. In the manufacturing industry, how to avoid environmental pollution and reducing energy consumption are the main issues facing the manufacturing industry in the 21st century. Therefore, as a softening technology to improve the way raw materials are used, it should be developed in harmony with the economy, resources, and environmental protection (Hill 2007). On the one hand, it is necessary to strengthen the use of low-quality materials and improve the utilization rate of materials; on the other hand, it is necessary to change the processing technology of raw materials, reduce the waste of materials, and reduce the use of dangerous substitutes (Goldhahn et al. 2021).

At present, as an environmentally friendly and economical method, hydrothermal modification in different softening media is one of the most important methods in softening heat treatment technology (Endo et al. 2016). It is also a promising alternative to the traditional chemical treatment of wood. In the field of wood modification, heat treatment is the most commercially advanced wood modification process (Hill 2007). Some foreign companies combine water heating and other processes with changing the properties of wood, such as Plato (NL), Bingaman (www.bingamanlumber.com), Thermory (www.thermoryusa.com). The process and requirements of this kind of wood heat treatment are very different from those of wood softening treatment, but the mechanism of action on wood is indeed the same. Therefore, relevant process parameters can be adjusted to achieve wood softening requirements. Hydrothermal softening of wood is generally considered an environmentally friendly process because it does not use any chemicals. But for large-scale production, such evaluations are too limited and do not take into account the nature of the relevant substances produced during processing (Militz and Lande 2009, Retfalvi et al. 2009), and the input cost of the whole hydrothermal softening. By sorting out previous studies, it is found that there are few studies on the environmental impact of hydrothermally softened wood, and future studies can fill this gap (Ali et al. 2021).

The trend of going intelligence

In the future, intelligent manufacturing will be based on industrial big data, experience, and knowledge, make intelligent decision-making and execution, and make dynamic self-adaptive adjustments according to the environment and state. For example, in the field of wood softening, experimental data and production data can be collected and analyzed. Data can be collected and analyzed for the optimal parameters of softening when the tree species and moisture content are determined. Different softening parameters can be formulated through data precipitation and sorting Mode, the setting of this mode is a parameter range determined according to a certain type of tree species or moisture content and other factors, within this range, the most suitable softening conditions can be matched to the softening object (Kois et al. 2014, Dedic et al. 2018, Mascarenhas et al. 2021). However, advanced manufacturing technology can

not only focus on process or process optimization but also need to have self-learning and decision-making functions (such as automatic adjustment of processing parameters after the machine re-identifies the object to reduce the scrap rate) to better promote the digital transformation of enterprises (Ozarska et al. 2013).

As a relatively new technology, microwave heat treatment has received certain attention in wood softening treatment. The main feature of this process is that heating, softening, bending, and drying are continuously carried out in the equipment, effectively improving production efficiency (Norimoto and Gril 1989). By systematically studying the relationship between wood dielectric properties, wood moisture content, microwave power density, wood grain direction, electric field direction, and microwave heat treatment technology, combined with the changes in the internal temperature, pressure, structure, and composition of the wood during the treatment process, the accuracy of the treatment effect can be achieved. Control (Xu et al. 2020). This is in line with intelligent production planning and control technology, which effectively improves production efficiency and quality and reduces operating costs.

Mascarenhas et al. (2021) summarized the related papers on microwave treatment of wood technology in recent years. According to the year of publication, about 68% of the submitted papers were published in the past ten years, which also indicates that the microwave treatment of wood technology is an ongoing and up-to-date research topic (Huang et al. 2007).

CONCLUSIONS

Wood softening has a critical impact on bending properties, forming shape, and yield. Softening treatment can increase the plasticity of the wood and make the bending process go smoothly, which is a key procedure before the wood is bent. According to the review of correlation research of softening treatment technology in wood bending, it can be determined that the softening technology of wood has become mature, but the mechanical processing production is relatively backward, which seriously hinders the development of bentwood products, in particular furniture. In the future, the advancement of technology and the development of furniture industrialization should be fully utilized to realize the gradual transition of wood bending technology from experimental small-scale to industrialized large-scale. The authors believe that in the development of the softening process, different technologies should be combined to improve the softening efficiency and softening effect of wood to ensure the low loss of wood performance to the greatest extent, effectively control the cost, and increase the choice range of wood, which will provide theoretical basis and practical guidance for scientific, rational, and efficient utilization of limited wood resources.

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