Ph.D. Thesis

Development of biodegradable biomass board and its mechanical properties using rice straw

(稲ワラを用いた生分解可能なバイオマスボードの開発及びその強度に関する研究)

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PREFACE

Biomass material is biological material derived from renewable raw materials, which is the product of plant photosynthesis with carbon dioxide. In modern history, petroleum and coal are indispensable materials for various industries. However, in the case of creating global environmental problems and increasing depletion, the fossil resources, petroleum and coal, must be replaced in the future. In addition, the supply of timer has been unable to catch up with the demands of global economy. It is more and more necessary to develop environment-friendly material. Biomass material is refined as renewable organic material, which is the product of plant photosynthesis with carbon dioxide and after the use it can be degraded into water and carbon dioxide by microbial action or reused as fertilizer through composting.

Crop straw is one kind of crop residues, which are defined as the nonedible plant parts and are left in the field after harvest. Every year, the amount of crop straw is tremendous; however, the availability is rare. The composition of crop straw contains cellulose and hemicellulose which makes straw products have certain physical strength, therefore, the products made of crop straw can replace some products made of wood, petroleum or coal. In addition, after use, it can be degraded into water and carbon dioxide by microbial action or reused as fertilizer through composting, which content the requirement of renewability. Hence, crop straw is considered as an environment-friendly biomass material.

At the end of 1970s, the British invented rice straw particle board. In the 1980s, the rice straw particle board was began to be produced. The production technology was named “Compark Technology” and the he rice straw particle board was named “Compark Board”. Currently, the production technology has been utilized by India, Pakistan, Sri Lanka, Indonesia, Philippines, Australia and other 10 countries. The production method was that: according to the different utilization requirements, different chemical adhesives were added to the rice straw chips, and the mixtures were made into biomass board by hot pressing. The disadvantage of the biomass board was that: because of containing chemical adhesive, the biomass board was not biodegradable and renewable material.

In this study, rice straw that was raw material was used to make biodegradable biomass board. The making processes of biomass board adopt the physical method, which are cutting, soaking, refining, forming and drying. The biomass board made in this study contains no chemical adhesives or chemical compounds. For these reasons, it will not cause any pollution to the environment. In order to investigate material properties of biomass boards, the three-point bending test and tensile test were performed, and rupture stresses of biomass boards were measured.

According to the result of this study, the rice straw biomass board was made successfully using the proposal method. And according to the mechanical properties of biomass board, it can be considered for applications in agriculture, packaging and building construction.

ACKNOWLEDGEMENT

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Zhang Jin

SUMMARY

With the rapid development of global economy, the supply of timber has been unable to meet the demand of economic development. At the same time, the rapid development of the economy led to oil and other fossil energy crisis, and plastics products are popular used in common life, which brought a very bad result called "the white pollution". It is serious harmful for human's health and natural environment. Therefore, composite materials with high performance, multi-function, and high added value, more and more eagerly need for human life and social development. Biomass material means that it is produced by renewable raw materials, which is the product of plant photosynthesis with carbon dioxide, and it can be degraded into water and carbon dioxide by microbial or light, or through the compost for fertilizer as natural polymers. Crop straw is considered as one kind of excellent biomass materials sources. At present, crop straws is faced the phenomenon with high yield, low utilization rate. But if it can be made into biomass board and could be used for agriculture, packaging industry, construction industry to replace wood products and plastic products. It is not only can ease the timber supply pressure, but also relieve the oil and other fossil energy supply pressure, and reduce plastic pollution to the environment, of course, the crop straws resources are more efficiently utilized.

The research is based on the conception of sustainable development and circular economic, refers to describe the process of make an environment-friendly, complete degradation of biomass material from the agricultural waste rice straw as raw material. There are two methods to produce the biomass board: physical and chemical methods. This study adopted the

physical method. The making process of biomass board was cutting, soaking, refining, forming and drying. The making method as follow;

At first, the rice straw was cut into small chips about 20mm by an ordinary cutter. Secondly, the chips were immersed water for 96 hours at room temperature. Then, the mixture of rice straw chips and water was refined by an electric refining device for 10 minutes. The fourth process was forming and drying. A compression mold was made into square with dimensions of 100 mm in length, 100 mm in width, 40 mm in depth for forming and drying. The whole forming and drying process took 2 hours and the experimental condition was 5 kinds of pressures from 2MPa to 8MPa and the drying temperature was 110℃. Finally, the rice straw pulp was made into a board which was named biomass board. 2 pieces of biomass boards were made under every experimental condition. As a result, 10 pieces of biomass boards were made successfully under 5 kinds of experimental conditions. In addition, the densities and moisture contents of biomass boards were measured. The density was in the range of 0.785g/cm^3~0.849g/cm^3. The moisture content was in the range of 5.25%~7.16%.

In order to investigate the appliance scope of biomass board, experiments measured mechanical properties which were three-point bending test and tensile test were carried out in this study. The experimental results show that the rupture stress of bending test was in the range of 9.73MPa~20.28MPa and the rupture stress of tensile test was in the range of 6.43MPa~10.89MPa. The results of this study showed that the biomass board was made successfully using the proposed method without any chemical adhesives or chemical reagents and the biomass board had enough mechanical strength.

And then, this study further explored the heating temperature influence of the strength of the biomass board. The experimental condition was that the pressure was the same of 5MPa but the heating temperatures were 110℃、130℃、150℃、170℃、190℃. The results of this study showed that the densities were in the range of 0.83 g/cm^3~0.91 g/cm^3, the moisture contents were in the range of 3.78%~7.00%, the rupture stresses of bending test were in the range of 13.35MPa~19.62MPa and the rupture stresses of tensile test were in the range of 3.00MPa~17.22MPa. The results indicated that heating temperature affected the strength of the biomass board. The rupture stress increased with the increase of heating temperature.

In addition, the effect of different fiber length on mechanical properties of biomass board was investigated. The fiber length was 3 kinds which were 0mm<SF≤2.0mm, 2.0mm<MF≤4.0mm, 4.0mm<LF≤5.6mm. As in the above experimental conditions, the pressures were 2MPa, 3.5MPa, 5MPa, 6.5MPa, 8MPa and heating temperatures were all 110℃. The results of this study showed that the densities were in the range of 0.89 g/cm^3~1.02 g/cm^3 and 0.98g/cm^3~1.13g/cm^3 the moisture contents were in the range of 5.68%~6.46% and 5.66%~6.37%. And in the bending test, the SF biomass boards' rupture stresses were in the range of 15.15MPa~45.03MPa and the LF biomass boards' rupture stresses were in the range of 8.85MPa~35.97MPa. In the tensile test, , the SF biomass boards' rupture stresses were in the range of 6.32MPa~33.11MPa and the LF biomass boards' rupture stresses were in the range of 4.54MPa~11.80MPa.

From the result of this study, the rice straw biomass board was made successfully using the proposal method. The making process including cutting, soaking, refining, forming and drying was appropriate. No chemical adhesives or chemical compounds were added in whole making process of biomass board.

The biomass board made in this study is biodegradable and has enough mechanical strength, which is an environment-friendly material. Above all, the biomass board can replace wood products and plastic products in some place, and has broad application prospects in the production of plastic film, packaging, and building insulation.

Keyword: rice straw, biomass, biodegradable, rupture stress, cellulose

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CHAPTER 1. Introduction

1.1 Background and significance of this study

In the early 1900s, ***Bakelite***, the first fully synthetic thermoset, was reported by Belgian chemist Leo Baekeland who coined the term "plastics" by using phenol and formaldehyde. Plastic bring human many conveniences and can be used in a near infinite number of ways. In contrast, it threatens the environment as it is generally refined from fossil oil. Because of plastic's low cost, people use it without considering the effects. Efforts have been made to reduce its environmental impacts by shifting to the idea of sustainable development, but more effort needs to be made.

However, plastic brings human beings the large trouble. Plastic pollution involves the accumulation of plastic products in the environment that adversely affects wildlife, wildlife habitat, or humans. The prominence of plastic pollution is correlated with plastics being inexpensive and durable, which lends to high levels of plastics used by humans. However, it is slow to degrade. Plastic pollution can unfavorably affect lands, waterways and oceans. Living organisms, particularly marine animals, can also be affected through entanglement, direct ingestion of plastic waste, or through exposure to chemicals within plastics that cause interruptions in biological functions. Humans are also affected by plastic pollution, such as through the disruption of the thyroid hormone axis or hormone levels. In the UK alone, more than 5 million tons of plastic are consumed each year, of which an estimated mere 24% makes it into recycling systems. That leaves a remaining 3.8 million tons of waste, destined for landfills. Plastic reduction efforts have occurred in some areas in attempts to reduce plastic consumption and pollution and promote plastic recycling.

Therefore, composite materials with high performance, multi-functions, and high added value, are eagerly needed for human life and social development. “Biomass material” means that it is produced from renewable raw materials, which is the product of plant photosynthesis with carbon dioxide. After the use, it can be degraded into water and carbon dioxide by microbial action or reused as fertilizer through composting. Crop straw is considered to be one kind of environment-friendly biomass material source. At present, crop straw faces the situation of high yield, low utilization rate. However, if it could be made into biomass board and be used for agriculture, packaging industry, construction industry to replace wood products and plastic products, it not only can resolve the shortage of the wood supply, but it also can reduce the consumption of fossil resources, and decrease plastic pollution to environment. In consequence, crop straw resources should be utilized efficiently

1.2 What is biomass

Biomass is a term for all organic material that stems from plants(including algae, trees and crops). Biomass is produced by green plants converting sunlight into plant material through photosynthesis and includes all land and water based vegetation, as well as organic wastes. The biomass resource can be considered as organic matter, in which the energy of sunlight is stored in chemical bonds. When the bonds between adjacent carbon, hydrogen and oxygen molecules are broken by digestion, combustion, or decomposition, these substances release their stored, chemical energy. Biomass has always been a major source of energy for mankind and is presently estimated to contribute of the order 10-14% of the energy supply.

1.3 Definition of biomass material

Generally biomass is the matter that can be derived directly or indirectly from plant which is utilized as energy or materials in a substantial amount. "Indirectly" refers to the products available via animal husbandry and the food industry. Biomass is called as "phytomass" and is often translated bioresource or bio-derived-resource. The resource base includes hundreds of thousands of plant species, terrestrial and aquatic, various agricultural, forestry and industrial residues and process waste, sewage and animal wastes. Energy crops, which make the large scale energy plantation, will be one of the most promising biomass, though it is not yet commercialized at the present moment. Specifically biomass means wood, Napier grass, rape seed, water hyacinth, giant kelp, chlorella, sawdust, wood chip, rice straw, rice husk, kitchen garbage, pulp sludge, animal dung etc. As plantation type biomass, eucalyptus, hybrid poplar, oil palm, sugar cane, switch grass etc. are included in this category.

According to Oxford English Dictionary, it was in 1934 that the term "biomass" appeared first in the literature. In Journal of Marine Biology Association, Russian scientist Bogorov used biomass as nomenclature. He measured the weight of marine plankton (Calanus finmarchicus) after drying which he collected in order to investigate the seasonal growth change of plankton. He named this dried plankton biomass.

Biomass is very various and the classification will be reviewed in 2.(1). Biomass specifically means agricultural wastes such as rice straw and rice husk, forestry wastes such as sawdust and saw mill dust, MSW, excrement, animal dung, kitchen garbage, sewage sludge, etc. In the category of plantation type, biomass includes wood such as eucalyptus, hybrid poplar, palm tree, sugar cane, switch grass, kelp etc.

Biomass is renewable resource and the energy derived from biomass is called renewable energy. However, biomass is designated as new energy in Japan and this naming is a legal term peculiar to our country. Law concerning promotion of the use of new energy was enforced in April of 1997. Though biomass was not approved as one of new energies at this moment, biomass was legally approved when the law was amended in January of 2002.

According to the law, power generation by photovoltaics, wind energy, fuel cell, wastes, and biomass as well as thermal use of waste are designated as new energy. Legally new energy is provided by the law what should be the production, generation, and utilization of petroleum alternatives, what is insufficiently infiltrated by the economic restriction, and what is specially prescribed in order to promote the use of new energy by the government ordinance. In foreign countries, biomass is usually called and designated as one of renewable energies.

Many studies have suggested that biomass-derived energy will provide a greater share of the overall energy supply as the price of fossil fuels increase over the next several decades. The use of biomass a source of energy is very attractive, since it can be a zero net CO2 energy source, and therefore does not contribute to increased greenhouse gas emission. It is carbon neutrality of biomass, which is precisely described in 1.(2). The combustion of biomass energy results in the emission of CO2, however, since nearly all of the carbon in the fuel is converted to CO2, just as it is during the consumption of fossil fuels. The zero net CO2 argument relies on the assumption that new trees, or other plants, will be replanted to the extent that they will fix any CO2 released during the consumption of biomass energy. This may well be true for the properly managed energy plantations, but is not likely to pertain in many developing countries where most of the biomass energy is obtained from forests which are not being replanted, at least not to the same degree that they are being harvested.

The widespread expansion of biomass energy use may result in significant concerns about availability of land, which may otherwise be used for food production, or other commercial use such as timber production. Recent reports showed that a wide range of estimates of future biomass energy potential, ranging from the current level of approximately 42 EJ to nearly 350 EJ close to the current level of total energy production by the year 2100. Consequently, it is desired that biomass energy should be wisely utilized in accordance with the food or valuable material production as well as environmental preservation.

Biomass is quite various and different in its chemical property, physical property, moisture content, mechanical strength etc. and the conversion technologies to materials and energy are also diversified. Researches which make it possible to develop cost effective and environmentally friendly conversion technologies have been done to reduce the dependence on fossil fuels, to suppress CO2 emission, and to activate rural economies.

1.4 Utilization of biomass material in the world

In the 21st century, in the field of material science, biomass material receives more and more attention. The research of biomass materials in the worldwide emerged in the 1960s, due to its commitment to improve and protect the ecological environment. So governments and research institutions payed attention to its development and utilization, and biomass material got rapid development in the 1980s. People created many new biological material with physical, chemical or mechanical method, such as plastic wood, restructuring wood, laminated board, straw board and so on.

Plastic wood is a new type wood which was created in 1961. In the past few decades, many scholar has carried on study of the plastic wood about its choice of monomer, production method, technological process, physical and mechanical properties, processing performance, and so on. Restructuring wood originated from the idea of John Douglas Coleman who was the scientist of Australian Commonwealth Scientific and Industrial Research Organization. Over the next few decades, many countries has applied for patents about restructuring wood. In 1985-1988, a factory about restructuring wood was built, which marked the industrial production beginning of restructuring wood.

Laminated board was caught the attention by mankind which was invented in the United States. Since 1985, in north American, laminated boards was be used for building. In 1980, Japan Atlon Company issued patents of wood-plastic composite (WPC) and promoted in the worldwide. This practical new technology is the one which developed rapidly and has remarkable economic benefits. In 1983, American Woodstock Company began to produce automotive interior floor device by Italian extrusion technology which used polypropylene and 50% wood powder for extruding molding. The product is an early application of WPC in U.S.. In the early years of 1990s, the United States Trex company began to produce composite materials used PVC and 50% wood fibers mainly for building doors and windows. In 2000, Japanese Ministry Of Agriculture, Forestry & Fisheries was the first country promoted “Biomass Materials. Japanese Comprehensive Strategy”. The utilization and development of biomass materials has being researched as the central topic in many countries such as United States, India and so on.

1.5 The utilization of rice straw

1.5.1 The background of rice

Rice (*Latin name: Oryza sativa*) is a genus of perennial grass in the poaceae (grass family) that originated in India, Thailand, and southern China, was domesticated and diversified in ancient times, and is now cultivated in wet tropical, semi-tropical, and warm temperate areas around the world for the production of its cereal grain. Rice is one of the two most important cereal crops world for human consumption; the other is wheat, Triticum species. (Corn, Zea mays, is produced in larger amounts, but a sizable portion of it is used for livestock feed and making ethanol for biofuel). Rice is cultivated on an estimated 3% of the world's agricultural land, and serves as a primary source of calories for over half the world's population.

Rice is generally an annual grass. Plants typically grow in a tuft (clump) of upright culms (stems) up to 2m or more tall, with long, flat leaf blades. The flowers grow on broad, open terminal panicles (branched clusters). The oblong spikelet, which each contain a single flower (that develops into a single kernel of grain), are sparse along the stem rather than forming dense clusters. The structure of rice straw is showed in Fig.1-1.

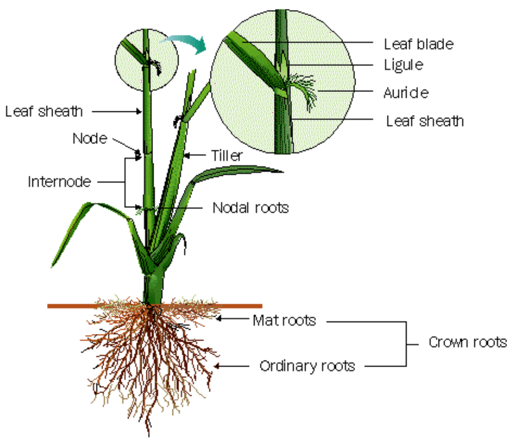


Fig. 1-1 The structure of rice straw

Rice has hundreds of cultivars with different grain color, size, and shape, as well as environmental tolerances and seasonality—the types are generally categorized as valley rice, upland rice, spring rice, and summer rice. It is generally grown in fields that are flooded for part of the growing season—whether from irrigation (the majority of cultivation), rainfed or floodplain systems--which help reduces competition from other plants, among other benefits; some upland varieties can be grown without flooding, but they account for only 4% of rice cultivated worldwide.

Rice is thought to have been domesticated in India and brought to China by 3,000 B.C. It was cultivated in Babylon and the Middle East by 2,000 years ago, and spread to the Europe during medieval times.

The FAO estimates that the total commercial harvest of rice in 2010 was 672.0 million metric tons, harvested from 153.7 million hectares. China and India were the leading producers, followed by Indonesia, Bangladesh, and Vietnam.

1.5.2 The chemical structure of rice straw

Rice is an important food crop in the world. Every year, tremendous rice was cultivated which led to a large of rice straw. But only a small fraction of rice straw was used for paper making, the remaining rice straw for industrial utilization was very little. The main chemical structure of rice straw is showed in Table 1-1.

Rice straw with ash and pectin, such as the relative density is small, less than the density of cellulose, particle size range is only 0~4mm. Mechanical properties of rice straw on the operation is difficult, because of its thin wall, high shrinkage rate, more difficult to make mechanics specimen. Around the average moisture content of 50%, the edge of the straw began to dry shrinkage, rolled into multi-layer tubular, measuring fixture is difficult to clamping, so difficult determination of cross-sectional area.

Table 1- 1 The main chemical structure of rice straw

Item	Composition (% w/w)*
Cellulose	39.2
Hemicellulose	23.5
Lignin	36.1
Ash	12.4
Total sugars	0.071
Total carbon	41.8
Total nitrogen	0.457

*(% w/w) = Percent based on dry weight

Rice straw fiber is short and thin. Its average length is less than 1 mm, and width is only about 8 microns. Cellulose mainly exists in the cell wall, and rice straw on the cell wall has obvious horizontal grain section, the cell is very small, rather than the content of fibrous cells is very big, accounted for 54% of its surface area, mainly is the parenchyma cells, the shape of pillow shape, oval, square, polyhedron shape and amorphous small cell. Epidermal cells in the amorphous cells, short fiber, is fine. In the middle of rice straw, grass and grass fiber than stem cells, these characteristics led to in the process of biomass using rice straw board, the difficulty of increasing, plank fiber combination of not easy. Different parts of rice straw fiber length is as shown in Table 1-2.

Table 1- 2 The different parts of rice straw fiber length

	Length/mm				Width/μm			
	Ave.	Max.	Min.	Common	Ave.	Max.	Min.	Common
Ensemble	0.92	3.07	0.26	0.47～1.43	8.1	17.2	4.3	6.0～9.5
Stem	1.00	2.13	0.47	0.75～1.17	8.9	20.6	4.3	6.5～12.9
Leaf	0.64	1.21	0.18	0.39～0.88	6.7	9.3	4.9	5.9～8.3
Node	0.33	0.68	0.14	0.20～0.46	9.9	14.7	4.9	7.4～13.7
Panicle	0.58	1.38	0.18	0.29～0.88	10.1	17.2	5.9	8.3～13.7

1.5.3 The utilization of rice straw

Rice straw is lignocellulose biomass material and can have many commercial uses for agricultural and industrial applications. Increasing environmental and public health concerns with conventional straw disposal methods, such as open-field burning, have made the alternative uses of straw attractive in many countries. Straw utilization must also allow for proper maintenance of soil organic matter and erosion control. The challenge is developing economically viable options that can produce and market straw products to offset the harvesting and processing costs. The extent of straw utilization is largely influenced by the local availability of competing feedstock sources for animals and biological conversion processes and prices of conventional fuels, such as coal and natural gas, for energy generation. The mostly developed uses of straw include: feeding animals, producing electrical power and heat via combustion and gasification, producing ethanol via microbial fermentation, producing methane via anaerobic digestion and so on.

However, rice straw has been rarely used for manufacturing composite or paper products or other structures.

Therefore, producing bio-board using rice straw is able to not only replace some products made of wood petroleum or coal but also protect the atmospheric environment. Until the 1940s, the technology which produced the modern building panels made of rice straw appeared. The production technology was pioneered in Sweden in 1930. After World War II, the British made a further development and promotion. The biomass board is rice straw as raw material. After being combed, rice straw was made into board by hot pressing. And then, two pieces of cardboards were pasted on both sides of the board. Currently, there are more than 30 countries in the world to produce the rice straw board and the production capacity is more than 80 million m3 annually. The board has the disadvantage that: high wastage rate of raw material, poor water proofing property and the requirement of cardboards.

At the end of 1970s, the British invented rice straw particle board. In the 1980s, the rice straw particle board was to be produced. The production technology was named "Compark Technology" and the rice straw particle board was named "Compark Board". Currently, the production technology has been utilized by India, Pakistan, Sri Lanka, Indonesia, Philippines, Australia and other 10 countries. The production method was that: according to the different utilization requirements, different chemical adhesives were added to the rice straw chips, and the mixtures were made into biomass board by hot pressing. The disadvantage of the bio-board was that: because of containing chemical adhesive, the biomass board was not biodegradable and renewable material.

CHAPTER 2. Biomass Board making process

2.1 Introduction

With the rapid development of the global economy, the supply of wood has been unable to meet the demands for economic growth. At the same time, the rapid development of the economy led to oil and other fossil resource crises. Simultaneously plastic products are popular used in daily life. This has brought a very bad result called "the trash-plastic-pollution", which is serious harmful for human’s health and natural environment. Therefore, composite materials with high performance, multi-functions, and high added value, are eagerly needed for human life and social development. “Biomass material” means that it is produced from renewable raw materials, which is the product of plant photosynthesis with carbon dioxide. After the use, it can be degraded into water and carbon dioxide by microbial action or reused as fertilizer through composting. Crop straw is considered to be one kind of environment-friendly biomass material source. At present, crop straw faces the situation of high yield, low utilization rate. However, if it could be made into biomass board and be used for agriculture, packaging industry, construction industry to replace wood products and plastic products, it not only can resolve the shortage of the wood supply, but it also can reduce the consumption of fossil resources, and decrease plastic pollution to environment. In consequence, crop straw resources should be utilized efficiently.

Worldwide, rice is the most important agricultural product. Hence, every year, the production of rice straw is more than 600 million tons, including 300 million tons in China. However, in most rice growing areas around the world, up to now, the traditional method of disposing rice straw is to burn it. This practice is responsible for air pollution. Therefore, rice straw is one kind of positive biomass material.

This research is based on the conception of sustainable utilization of biomass resources. An environment-friendly, complete degradable biomass material should be developed. Making degradable biomass board from rice straw is considered in this study. The manufacturing processes of biomass board adopt the physical method, which are cutting, soaking, refining, forming and drying. The biomass board made in this study contains no chemical adhesives or chemical compounds. The biomass board used can be degraded completely as fertilizer that is absorbed by microbes. For these reasons, it will not cause any pollution to the environment. In order to investigate the biomass material properties, the bending test is performed, and rupture stresses of biomass boards are discussed.

2.2 Basic principle for fiber bonding

2.2.1 The property of cellulose

Cellulose is an organic compound with the formula$(C_6H_{10}O_5)_n$, shown in Fig.2-1, a polysaccharide consisting of a linear chain of several hundred to many thousands of $\beta(1\rightarrow4)$ linked D-glucose units and is an important structural component of the primary cell wall of green plants. It is the most abundant organic polymer on Earth. Every year, vegetation can produce about 10.6 billion tons of cellulose.

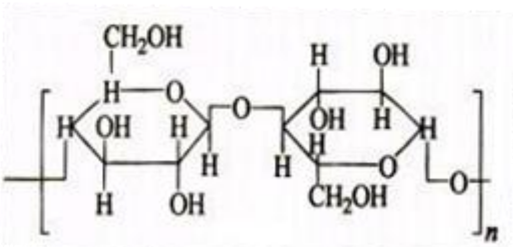


Fig.2- 1 The formula of cellulose

2.2.2 The chemical compositions of rice straw

The rice straw mainly consists of 36% cellulose, 18% hemicellulose and 14% lignin, 14% ash content and so on.

Comparing with timber, rice straw has the following characteristics:

(1) The ash content is high. Its main composition is SiO_2 which forms a non-polar surface in the fiber, so that affects the formation of hydrogen bonds and reduces the adhesion strength;

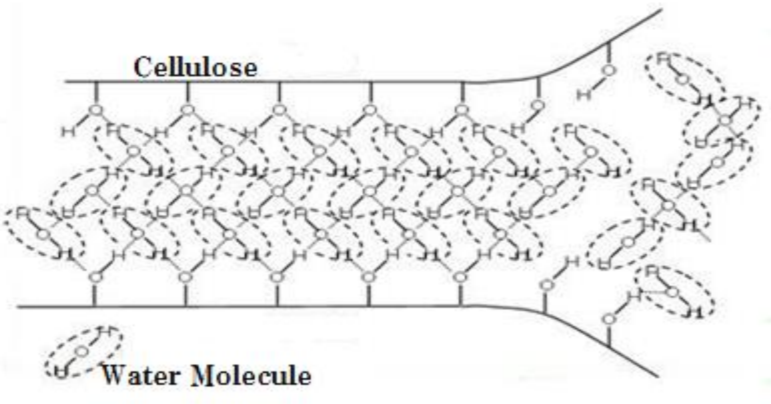
(2) The ether extract content is high. Its main composition is fat, wax and resin of plant fiber, which mainly is on the surface of rice straw, so that influence factors straw cementing performance, too;

(3) The lignin and cellulose content is low. Cellulose is the main component of plant fiber cells. Lignin is in the sides of the fiber which makes the fiber bonding unity each other.

Therefore, it is certain difficulty to making biomass board using rice straw by physical methods.

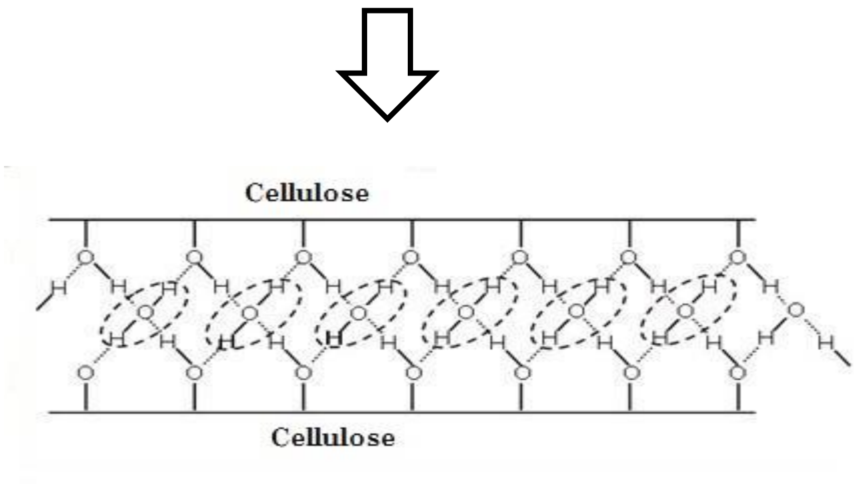
2.2.3 Basic principle of biomass board forming

From the formula of cellulose in Fig.2-1, there are three hydroxyls (glucose) in every cellulose chain polymer structure unit, so each cellulose molecules has three times the degree of polymerization of hydroxyl groups. The total reached more than tens of thousands. These hydroxyl have great hydrophilic, so when the plant fiber were purified and dispersed in water, the numerous hydroxyl of the cellulose molecules can absorbing water, and make the fiber swelling. When the cellulose molecules near each other, two oxygen atoms of the adjacent molecular would bring water molecules to pull together, and the water molecules like connect two cellulose molecules bond, between the cellulose molecules built countless "water bridge". The combined process of cellulose molecules and water molecules is shown in figure 2-2. Therefore, the rice straw was cut into small chips and immersed water for 96 h at room temperature. The subsequent processes were carried out in the water. It is because, at room temperature and humidity environment, the fiber of rice straw can be refined rely on air and microorganisms which rice straw carried by itself, can also remove a small amount of, affect the mechanical strength of the board of biomass, hemicellulose, and can dissolve a small amount of, will greatly reduce the strength of the plate and the life of the lignin, may also soften the

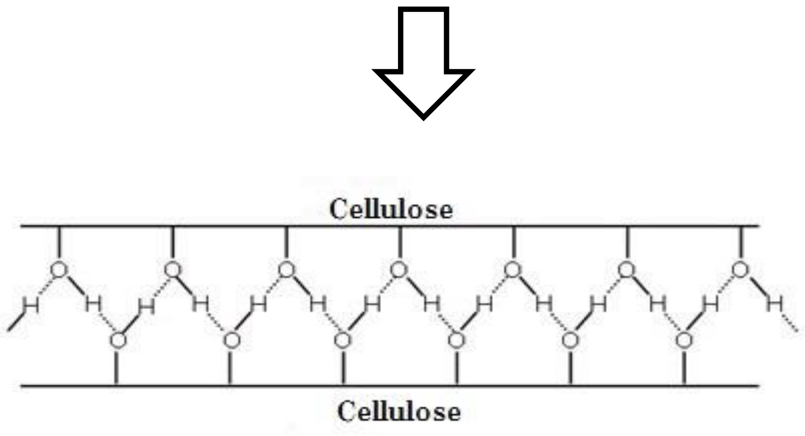


straw stalk cells intercellular layer.

a. Water-swelling



b. Forming a water bridge



c. Hydrogen bonding

Fig.2- 2 The binding process mechanism of cellulose and water molecules

2.3 Main tools for experiment

2.3.1 Refiner

Rice straws were separated into individual fibers using the refiner made by Satomi, which is showed in Fig.2-3. The parameters of the machine are list in table 2-1.

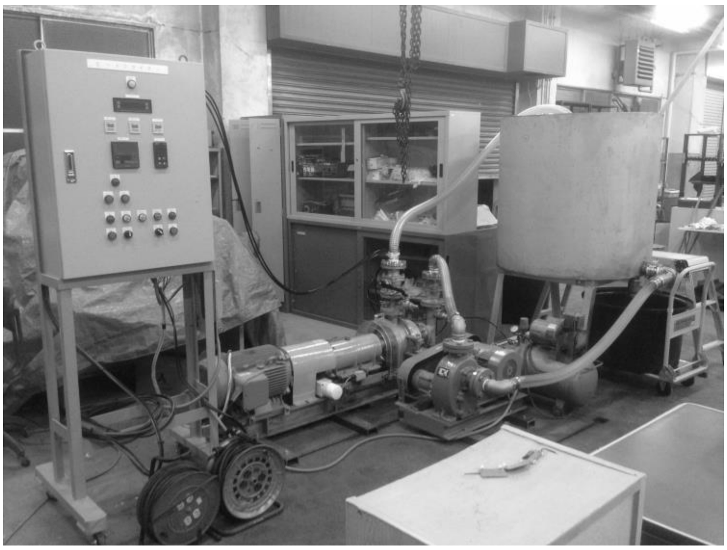


Fig.2- 3 Electric refiner

Table 2- 1 The parameters of refiner

Motor power	Cubage	6Hz-revolving speed	120Hz-revolving speed	Minimum input pressure	Maximum input pressure	Maximum output pressure
11-30kw	5-10t/d	0.52mm/min	10.51 mm/min	0.1MPa	0.35MPa	0.5MPa

2.3.2 Mold for forming

A compression mold was made into square with dimensions of 100mm×100mm×40mm. It had holes which were 2mm in diameter with an interval of 7mm×7m, in order to conducive to dehydration in the forming and drying process. Auxiliary molds as following:

1) removing board

2) metal mesh

3) copper

4) aluminous plate

5) two cupreous sticks

They were showed in Fig.2-4.

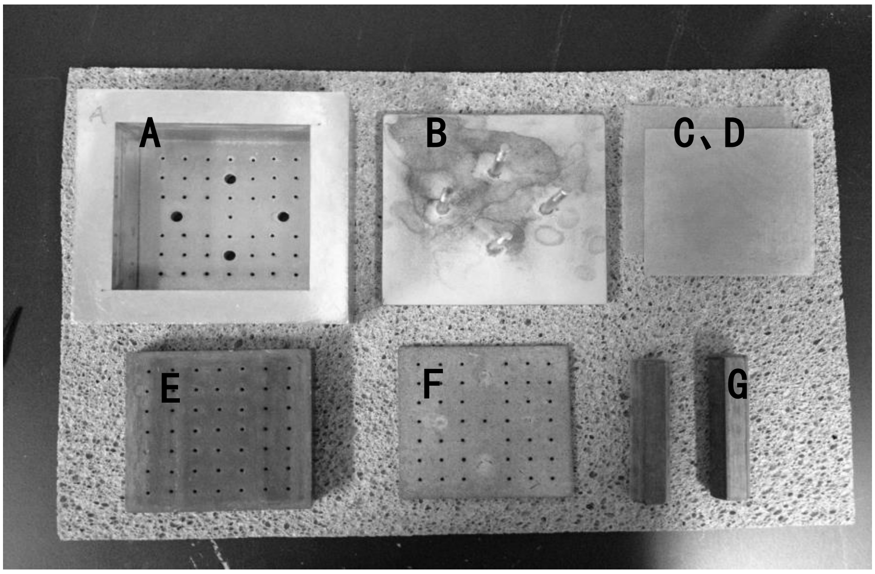


Fig.2- 4 The molds for forming

A-The compression mold; B-Removing board; C,D- Metal mesh; E-Copper; F- Aluminous plate; G- Two cupreous sticks

2.3.3 Thermal press

The compression process used a thermal press as shown in Fig.2-5.

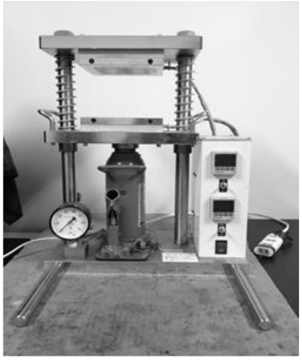


Fig.2- 5 The thermal press

The experiment machine main structure is: hydraulic jack, the heat conduction plates, temperature controller and pressure display monitor. The hydraulic jack lifted the down heat conduction plate for applying pressure and displayed real-time pressure on the pressure monitor. The heating temperature was adjusted by the temperature controller and displayed on the screen.

2.4 Preparation for experiment material

After harvesting the rice, dry rice straw was reserved for making biomass board. For pretreatment process, long rice straw were cut into small chips about 15mm when they were in a dry state and ground by an electric mixer for about 5 minutes. Rice straw fibers would be separated in accordance with the length of rice straw fiber is about 1~3mm. Second, the chips were immersed water for 96 hours at room temperature. Table 2-2 shows the experimental conditions for making biomass board using rice straw in this study.

Table 2- 2 The experimental condition for making biomass board

No.	Soaking	Refining	Forming and drying		
	Time/h	Time/min	Maximum Pressure/MPa	Temperature/℃	Time/h
A	96	10	2.0	110	2
B	96	10	3.5	110	2
C	96	10	5.0	110	2
D	96	10	6.5	110	2
E	96	10	8.0	110	2

In this study, 5 biomass boards named A, B, C, D, E were made by the same heating temperature 110℃ and different temperature in the process of forming and drying. 5 levels of the maximum applied pressure 2.0MPa, 3.5MPa, 5.0MPa, 6.5MPa and 8.0MPa were applied on biomass boards.

2.5 Making biomass board

After harvesting the rice, dry rice straw was reserved for making biomass board. The flowchart shown in Fig.2-6 is the whole process of making biomass boards. First, the rice straw was cut into small chips about 15mm by an ordinary cutter as shown in Fig.2-6. Second, the chips were immersed water for 96 h at room temperature as shown in Fig.2-7. Then, the mixture of rice straw chips and water was refined by an electric refining device for 10 min, so that the fibers of rice straws were separated into individual fibers using the refiner as shown in Fig.2-8 and Fig.2-9. On the one hand, during the refining, the macromolecule fibers were refined into microfibers. On the other hand, it exposed more active hydroxyl groups and laid the foundation for physical adsorption, which was good for separated fibers to recombine each other in the next forming process. The fourth process was forming and drying. A compression mold was made into square with dimensions of 100 mm in length, 100 mm in width, 25 mm in depth. In order to conducive to dehydration in the forming and drying process, it also required some auxiliary tools with dimensions of 100mm×100mm including two metal meshes, a copper block and an aluminum plate. The compression mold, the copper block and the aluminum plate all had holes which were 2mm in diameter with an interval of 7mm×7mm. During the forming process, pressure was applied gradually and 1/4 of maximum pressure was loaded every 0.5 h. The whole forming and drying process took 2 h at a temperature of 110℃. Finally, the rice straw pulp was made into a board which was named biomass board. During forming and drying process, the exposed active hydroxyl groups recombined with the hydrogen bonds in water, so that the fibers were reunited and biomass boards were formed. Figure 1 shows the flowchart of making process of biomass board.

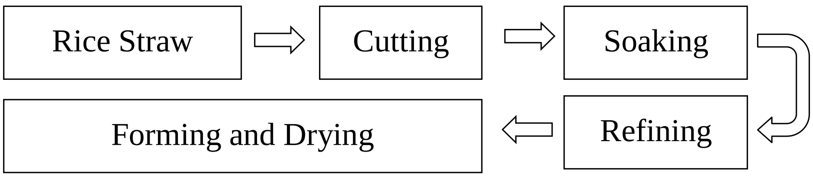


Fig.2- 6 The process of making biomass board

Fig.2- 7 The chips were cut by an ordinary cutter

Fig.2- 8 The chips were soaked

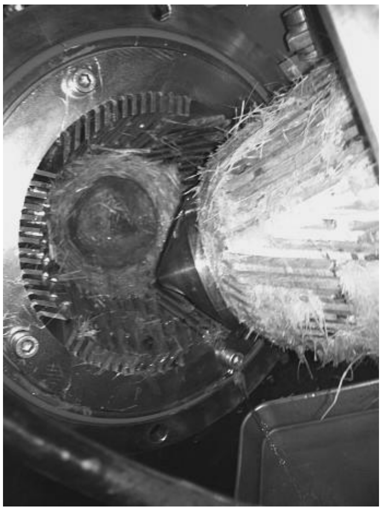


Fig.2- 9 The straw on refining

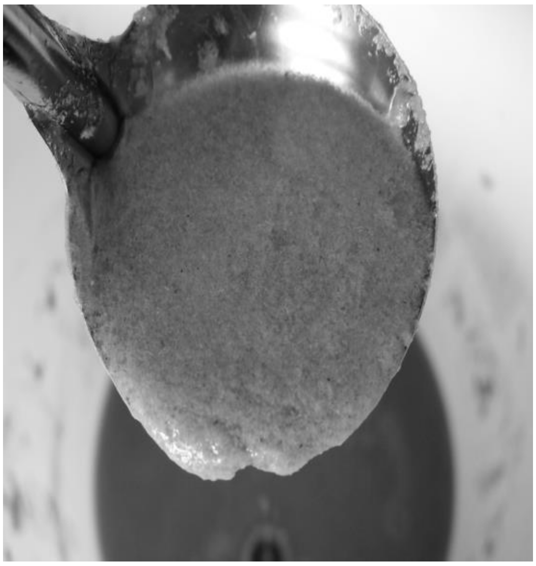


Fig.2- 10 The straw after refining

2.6 Measurement of density and moisture content

After the biomass boards were made successfully, the sizes of them were measured for density. There were evenly three points of every board's length were measured, namely, L1, L2, L3; There were also evenly three points of every board's width were measured, namely, D1, D2, D3; There were evenly eight points of every board's thickness were measured, namely, H1, H2, H3, H4, H5, H6, H7, and H8.The measurement method is showed in figure 2-11 schematic diagram.

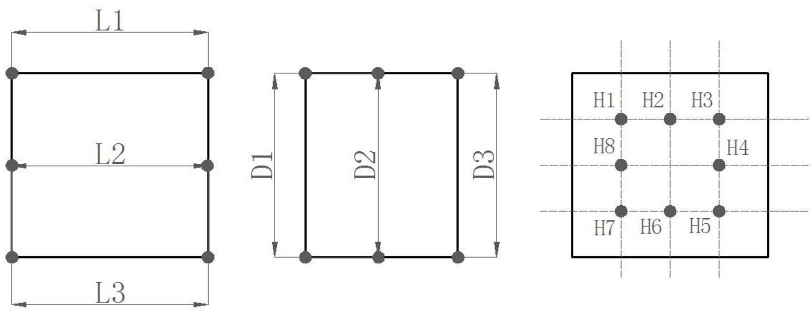


Fig.2- 11 Schematic diagram for measuring biomass boards

The moisture content of biomass board in this study is an important physical parameter of bio-based materials. In this study, the moisture content of every biomass board was measured. The moisture content was calculated by Equation (2.1).

$$W = \frac{M_c - M_b}{M_b - M_a} \times 100\% \tag{2.1}$$

Where, M_a W is moisture content; M_a is the quality of the container; M_b is the total quality of the container and specimen before drying; M_c is the total quality of the container and specimen after drying.

2.7 Strength test

The rice straw biomass boards were complex non-homogeneous materials so that the mechanical properties of biomass boards must be examined carefully. In order to investigate mechanical properties of the biomass boards, the three-point bending test and tensile test were carried out in this study. A universal material testing machine was used for the two tests as shown in Fig.2-12.

Four specimens were cut for bending test and three specimens were cut for tensile test from every biomass board. The specimens were rectangle with dimensions of 10mm×50mm. Both ends of specimens were supported, and force was loaded at the center of the specimens until fracture. Stress (σ) was obtained by the results of the bending test to confirm the mechanical properties of the biomass boards.. It collected electrical signals in the test and changed them into load (N) and deflection (mm). The rupture stress was calculated by Equation (2.2).

$$\sigma_{\mathrm{b}} = \frac{3Wl}{2bh^2} \tag{2.2}$$

Where, σ_b is bending stress; W is load applied; l is supported span; b is width of specimen; h is thickness of specimen.

The dimensions of specimens for tensile test were shown in Fig.2-13. The universal testing machine was used for measuring load (N) and elongation (mm). Tensile stress σ_b was obtained by the results of the tensile test. The stress was calculated by Equation. (2.3).

$$\sigma_{\mathrm{t}} = \frac{W}{bh} \tag{2.3}$$

Where, σ_t is tensile stress; W is load applied; b is width of experimental area; h is thickness of experimental area.

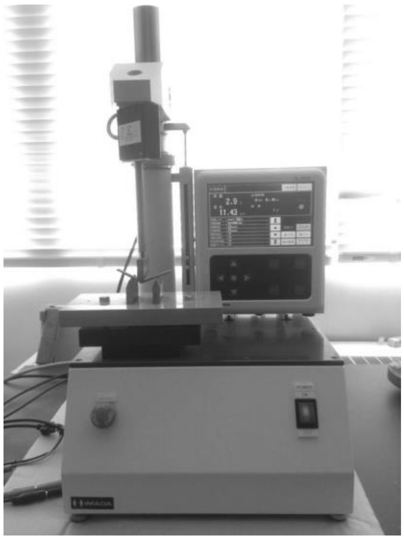


Fig.2- 12 Universal material testing machine

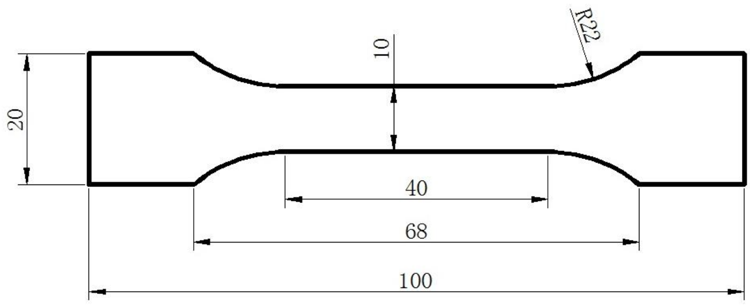
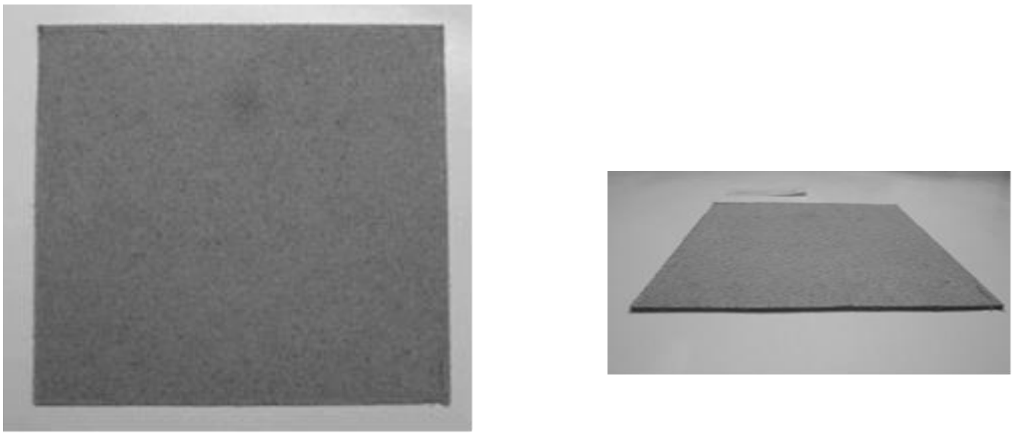


Fig.2- 13 The specimen size of tensile test

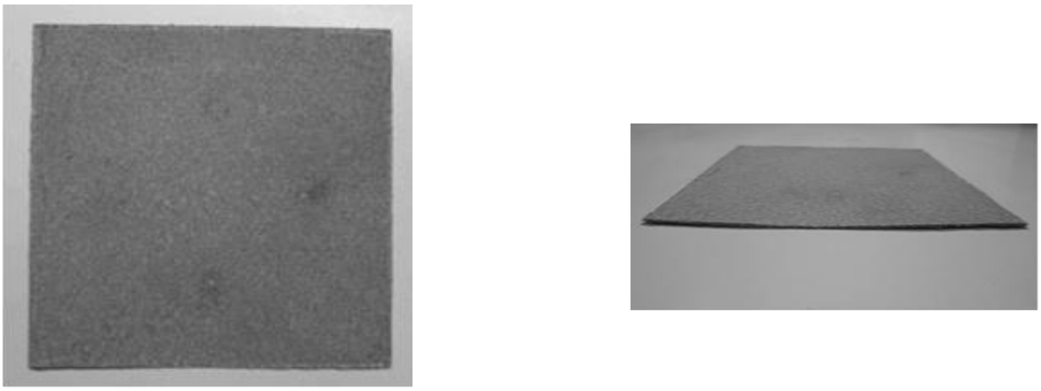
2.8 Results

2.8.1 Results of making biomass board

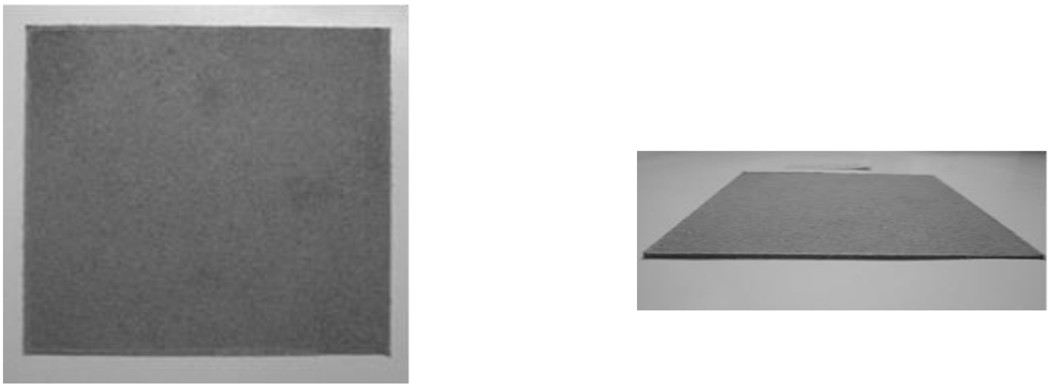
In this study, rice straw was used to make biomass boards. Cutting, soaking, refining, forming and drying were carried out to complete the biomass boards. 5 pieces of biomass boards were made at different maximum applied pressures. Making 5 pieces of biomass boards named Board A, Board B, Board C, Board D, Board E was successful at every experimental condition proposed in this study. The result of the experiment indicates that the processes of cutting, soaking, refining, forming and drying are appropriate for making biomass boards using rice straw. Fig.2-14 shows the biomass boards.



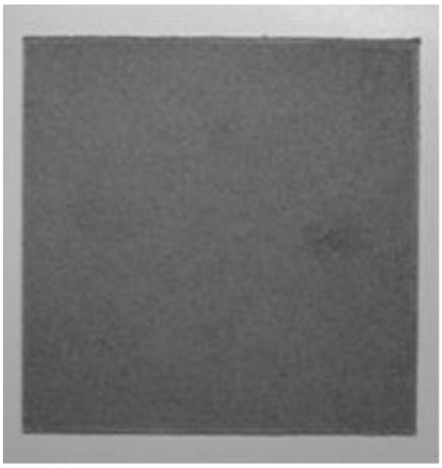
a. biomass board A (applied pressure was 2.0MPa)

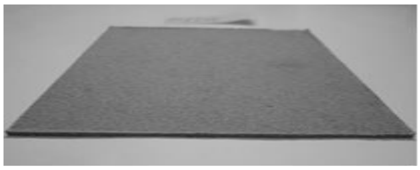


a. biomass board B (applied pressure was 3.5MPa)

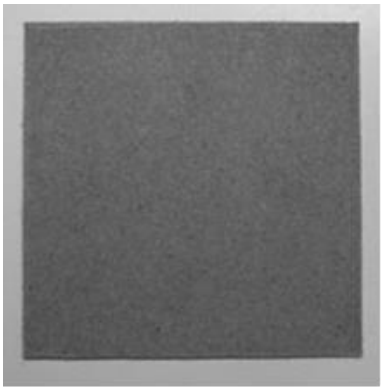


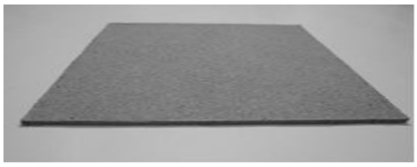
b. biomass board C (applied pressure was 5.0MPa)





c. biomass board D (applied pressure was 6.5MPa)





d. biomass board E (applied pressure was 8.0MPa)

Fig.2- 14 The biomass boards were made of 5 kinds of applied pressures

2.8.2 Results of moisture content and density

According to the measurement method of Fig.2-13, the dimensions of biomass boards were shown in Table 2-3.

According to the dimensions of biomass boards, moisture content and the density of biomass board were measured. The moisture content was in the range of 5.25%~7.16% and the average was 6.24%.The density was in the range of 0.785×10^3 ~0.849×10^3kg/m^3 and the average was 0.816×10^3kg/m^3.

Table 2- 3 The dimension of biomass boards

(a)

Board A	1	2	3	4	5	6	7	8	Ave.
L/mm	99.90	99.90	99.90						99.90
D/mm	100.00	100.00	99.95						99.98
H/mm	2.890	2.781	2.949	2.867	2.922	2.792	2.814	2.756	2.846
Mass/g	21.55								21.55
Density/ $10^3kg/m^3$									0.758

(b)

Board B	1	2	3	4	5	6	7	8	Ave.
L/mm	99.90	99.95	100.00						99.95
D/mm	99.95	99.90	100.00						99.95
H/mm	2.760	2.670	2.844	2.593	2.730	2.720	2.889	2.733	2.742
Mass/g	22.35								22.35
Density/ $10^3kg/m^3$									0.816

(c)

Board C	1	2	3	4	5	6	7	8	Ave.
L/mm	99.90	99.90	99.90						99.90
D/mm	99.90	99.95	99.90						99.92
H/mm	2.566	2.603	2.540	2.590	2.568	2.598	2.588	2.518	2.571
Mass/g	21.79								21.79
Density/									0.849

$10^3 kg/m^3$									

(d)

Board D	1	2	3	4	5	6	7	8	Ave.
L/mm	100.00	99.95	99.90						99.95
D/mm	99.90	99.90	99.85						99.88
H/mm	2.529	2.508	2.594	2.729	2.732	2.601	2.591	2.504	2.599
Mass/g	21.58								21.58
Density/ $10^3 kg/m^3$									0.832

(e)

Board E	1	2	3	4	5	6	7	8	Ave.
L/mm	99.90	99.90	99.90						99.90
D/mm	99.95	99.95	99.95						99.95
H/mm	2.686	2.522	2.593	2.491	2.520	2.547	2.662	2.554	2.572
Mass/g	21.21								21.21
Density/ $10^3 kg/m^3$									0.826

Fig.2-15 shows the values of moisture content and density of biomass board. Because the rice straw biomass board was made from natural fibers and the production process was the restructuring process of the rice straw fibers, the fibers distribution could not be precisely controlled and was uneven. Therefore, the density of each biomass board was different from each other. In addition, the moisture content increased with the increasing maximum applied pressure, but it is difficult to explore the real influence factors of moisture content at this time.

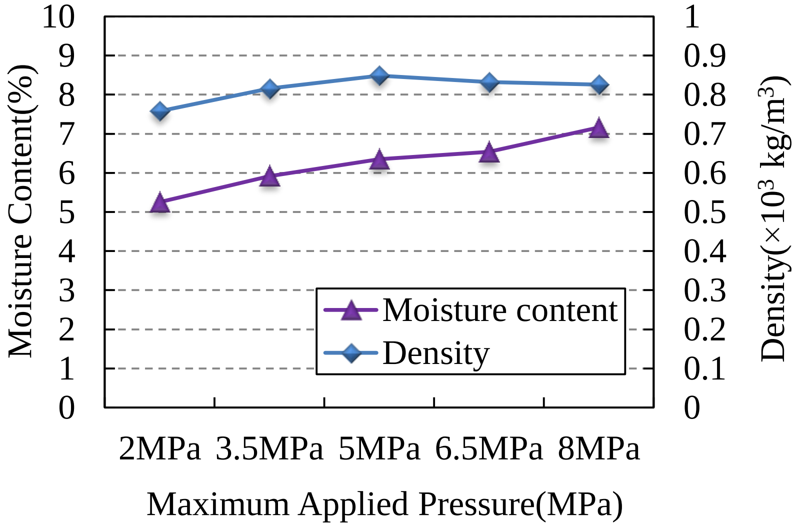


Fig.2- 15 Moisture content and density of biomass board

2.8.3 Results of three-point bending test

In order to investigate the mechanical properties of the biomass boards, the three-point bending test was carried out.

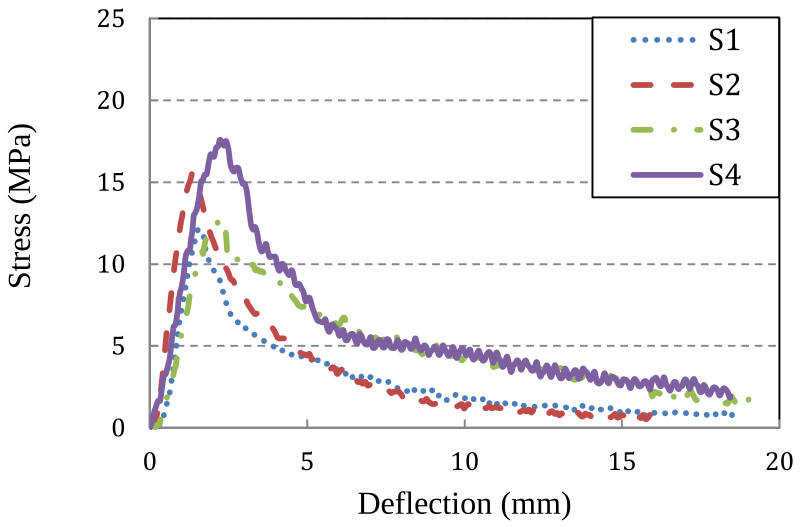
There were four specimens for bending test from every biomass board. The stress-deflection curves of bending test are shown in Fig.2-16. From biomass board A, the four specimens from biomass board A were named S-1, S-2, S-3 and S-4. According to the stress-deflection relation, for all of the specimens, the stress increased with the increase of deflection. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board A were 12.09, 15.54, 12.76 and 17.59MPa respectively. Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.

From biomass board B, There were four pieces of specimens named S-1, S-2, S-3 and S-4. According to the stress-deflection relation, for all of the specimens, the stress increased with the increase of deflection. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board B were 14.68, 12.51, 9.73 and 12.04MPa respectively. Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.

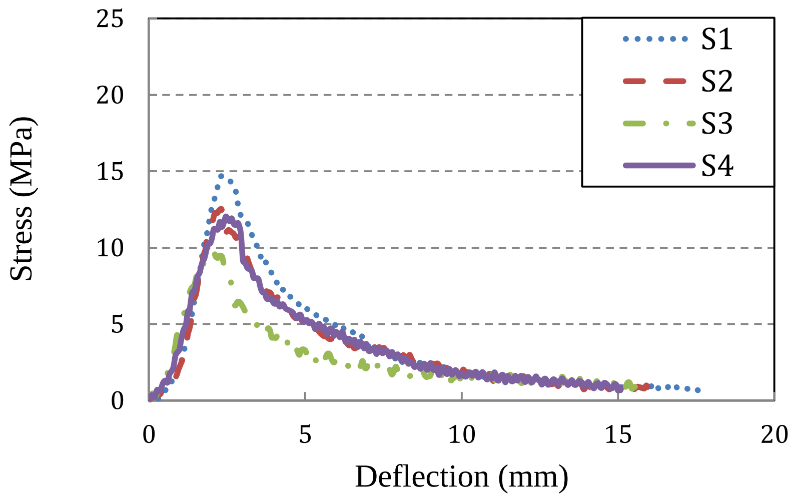
From biomass board C, There were four pieces of specimens named S-1, S-2, S-3 and S-4. According to the stress-deflection relation, for all of the specimens, the stress increased with the increase of deflection. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board C were 20.28,18.45,15.20 and 17.31MPa respectively. Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.

From biomass board D, There were four pieces of specimens named S-1, S-2, S-3 and S-4. According to the stress-deflection relation, for all of the specimens, the stress increased with the increase of deflection. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board D were 14.18,13.46,15.14 and 13.84MPa respectively. Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.

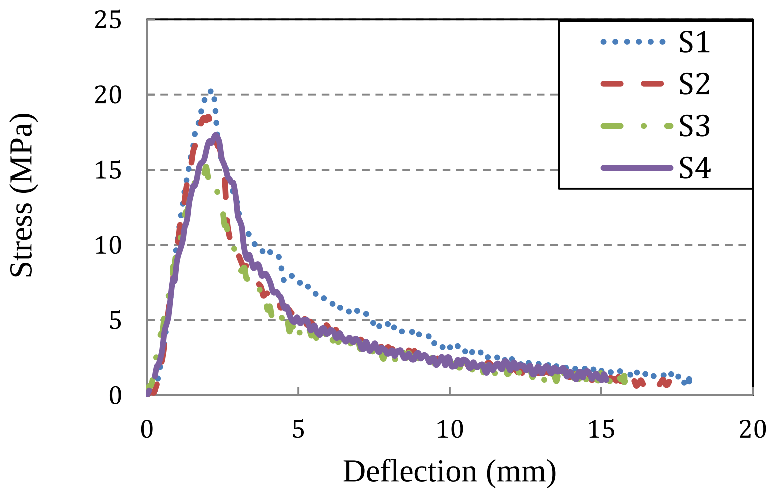
From biomass board E, There were four pieces of specimens named S-1, S-2, S-3 and S-4. According to the stress-deflection relation, for all of the specimens, the stress increased with the increase of deflection. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board E were 10.77,12.31,11.08 and 12.10MPa respectively. Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.



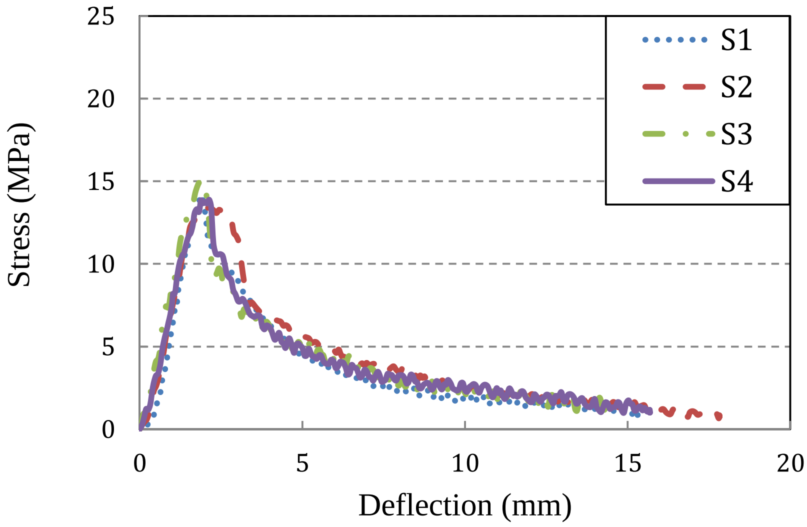
a. Stress-deflection curve of biomass board A



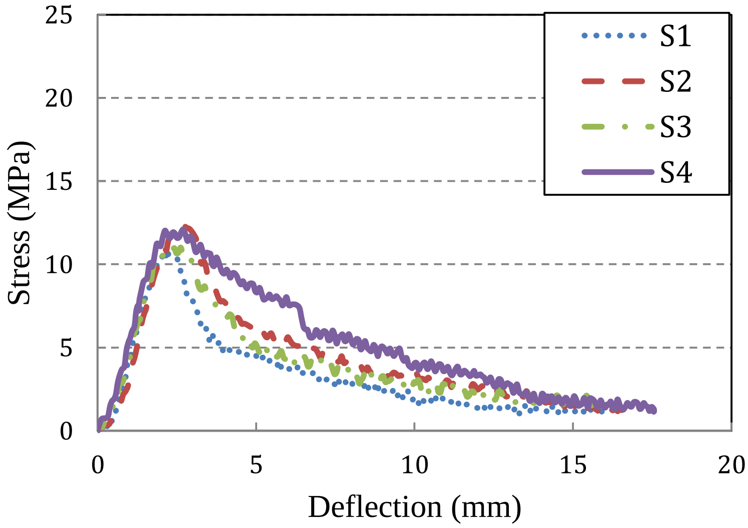
b. Stress-deflection curve of biomass board B



c. Stress-deflection curve of biomass board C



d. Stress-deflection curve of biomass board D



e. Stress-deflection curve of biomass board E

Fig.2- 16 The bending stress-deformation curve of biomass board

From the above result of bending test, the rupture stress of every biomass board is different from each other. Fig.2-17 shows the comparison of the rupture stresses of every biomass board.

The rupture stress is in the range of 9.73~20.28MPa, and the values of 5 biomass boards are 14.50MPa, 12.24MPa, 17.83MPa, 14.17MPa, and

11.56MPa.The average maximum rupture stress appears at maximum applied pressure of 5MPa which is 17.83MPa.

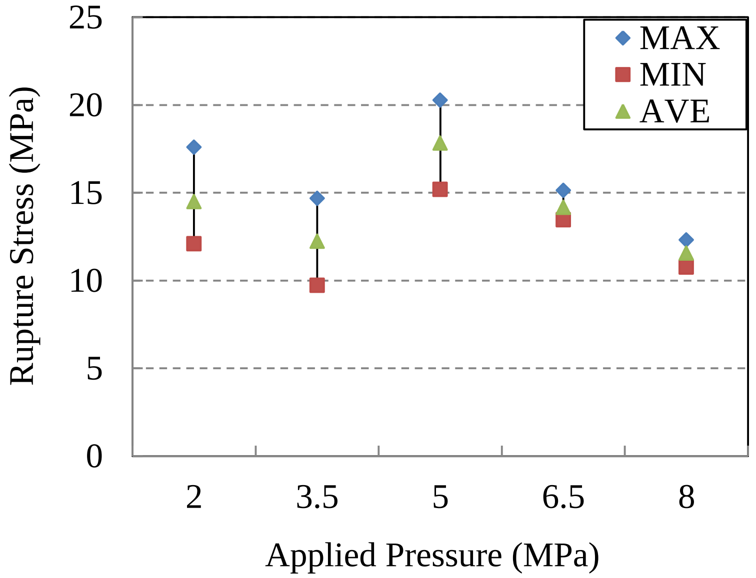


Fig.2- 17 Rupture stress of biomass boards

2.8.4 Results of tensile test

In order to investigate the mechanical properties of the biomass boards, the three-point bending test was carried out. Every biomass board was cut into four specimens The stress-deflection curves of bending test are shown in Fig.2-18.

From biomass board A, there were three pieces of specimens named S-1, S-2 and S-3. According to the stress- elongation relation, for all of the specimens, the stress increased with the increase of elongation. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board A were 4.71MPa, 6.30MPa, 8.83MPa respectively.

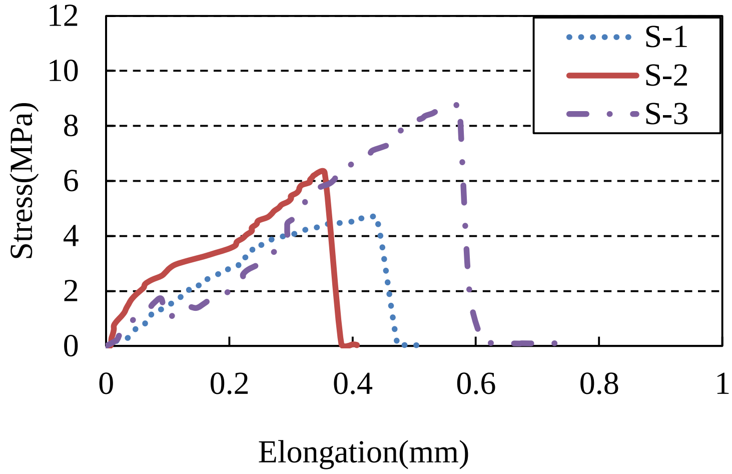
Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.

From biomass board B, there were three pieces of specimens named S-1, S-2 and S-3. According to the stress- elongation relation, for all of the specimens, the stress increased with the increase of elongation. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board B were 6.73MPa、5.03MPa and 6.50MPa respectively. Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.

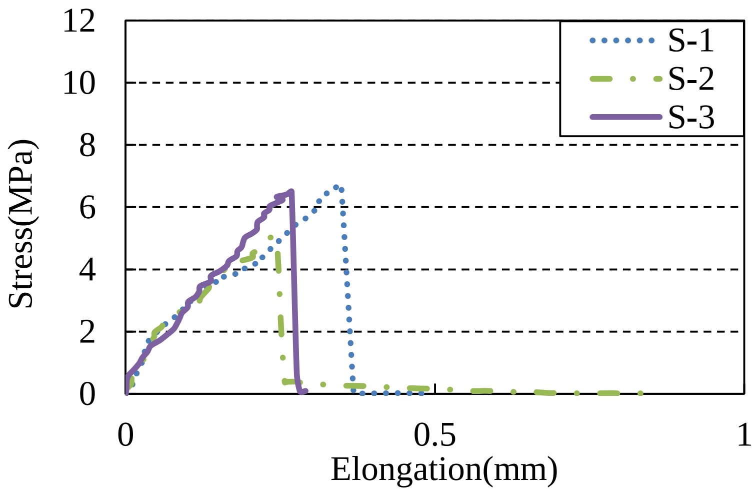
From biomass board C, there were four pieces of specimens named S-1, S-2, S-3 and S-4. According to the stress- elongation relation, for all of the specimens, the stress increased with the increase of elongation. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board C were 6.51MPa, 6.64MPa, 5.56MPa and 5.07MPa respectively. Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.

From biomass board D, there were four pieces of specimens named S-1, S-2, S-3 and S-4. According to the stress- elongation relation, for all of the specimens, the stress increased with the increase of elongation. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board D were 10.45MPa, 8.01MPa, 6.86MPa and 6.71MPa respectively. Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.

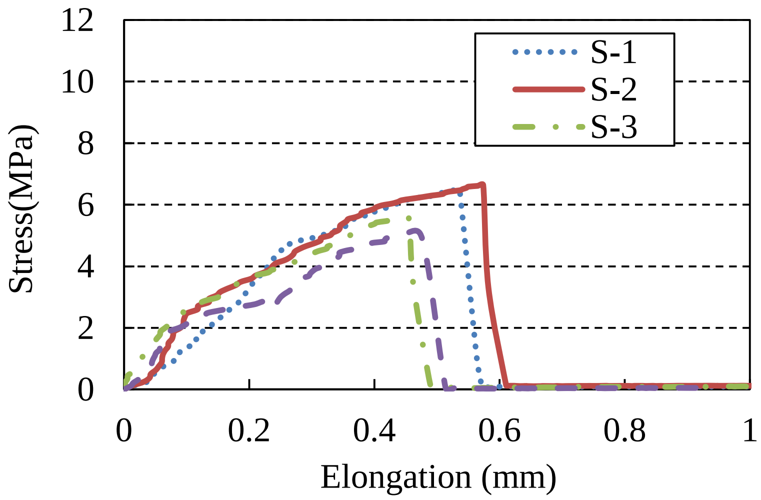
From biomass board E, there were four pieces of specimens named S-1, S-2, S-3 and S-4. According to the stress- elongation relation, for all of the specimens, the stress increased with the increase of elongation. When the stress reached the maximum value, specimens fractured. The maximum stress value of every specimen is named the “rupture stress”. After the stress reached the rupture stress, it decreased to zero slowly. That is because the specimen has still connected by some fibers when the fracture occurred. The remaining fibers still bear some load after specimens fractured. The rupture stresses of the four specimens from Board D were 8.91MPa, 9.15MPa, 9.80MPa and 9.90MPa respectively. Because of the non-homogeneity of fiber distribution, the intensity of one place was different from another place in the same biomass board.



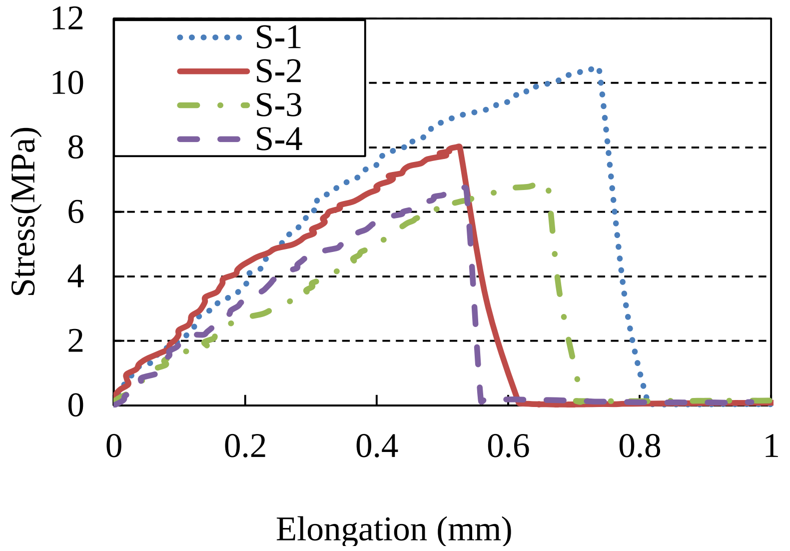
a. Stress-elongation curve of biomass board A



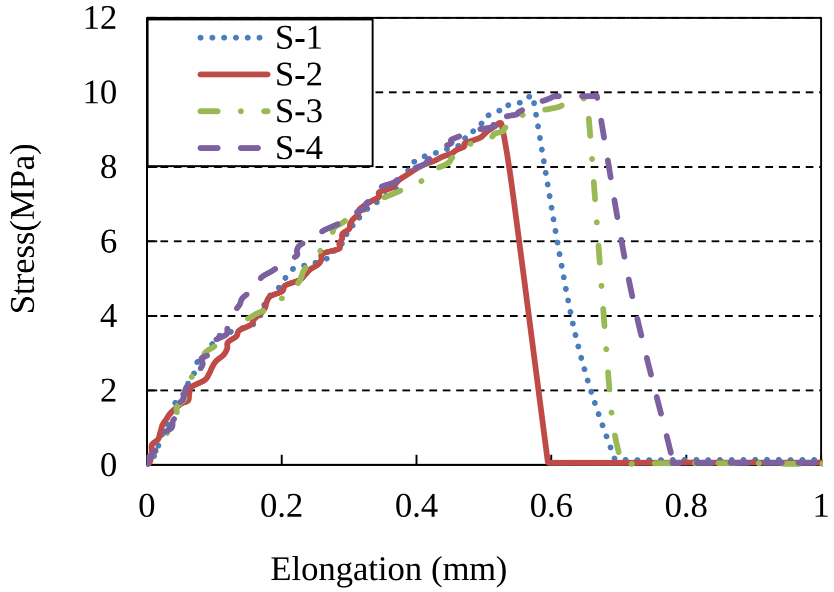
b. Stress-elongation curve of biomass board B



c. Stress-elongation curve of biomass board C



d. Stress-elongation curve of biomass board D



e. Stress-elongation curve of biomass board E

Fig.2- 18 Rupture stress of biomass boards

From the above result of bending test, the rupture stress of every biomass board is different from each other. Fig.2-19 shows the comparison of the rupture stresses of every biomass board.

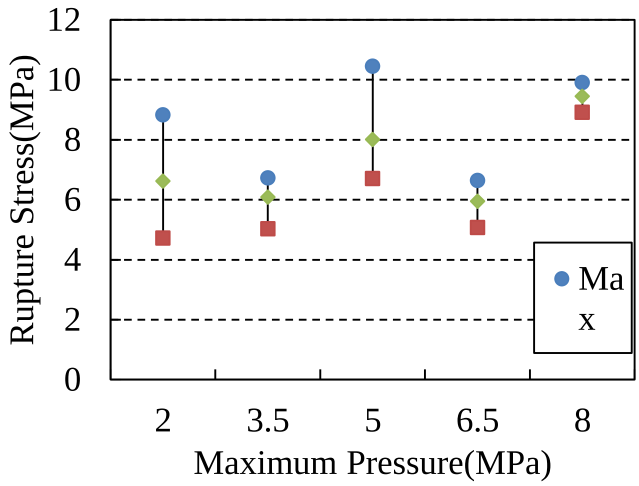


Fig.2- 19 Rupture stress of biomass boards

The rupture stress is in the range of 4.71~10.45MPa, and the values of 5 biomass boards are 6.61MPa, 6.09MPa, 8.01MPa, 5.94MPa, 9.44MPa.The maximum rupture stress appears at maximum applied pressure of 5MPa which is 10.45MPa.

2.9 Conclusions

In this study, biodegradable biomass board was made using rice straw by the process of cutting, soaking, refining, forming and drying. It can be concluded as follows:

1) The biomass board was made successfully using the proposed method. The manufacturing process consisting of cutting, soaking, refining, forming and drying is appropriate for general use. Mechanical method was adopted in the refining process of rice straw; therefore, the straw pulp is mechanical pulp. No

chemical adhesives or chemical compounds were added in the whole making process of biomass board. The biomass board made in this method is biodegradable, and an environment-friendly material.

2) The relationship between bending stress and deflection was obtained from the result of bending test. Technical evaluation showed that the rupture stresses of biomass boards were in the range of 9.73MPa to 20.28MPa; and the average values of rupture stress for 5 biomass boards are 14.50MPa, 12.24MPa, 17.83MPa, 14.17MPa, 11.56MPa. The maximum value of average rupture stress for 5 biomass board was 17.83MPa under the maximum applied pressure 5MPa. In this study, rupture stresses of the ordinary wrapping paper board used for packaging and polystyrene board used for food pallets were measured, which were 5.05MPa and 6.24MPa.

(3) The relationship between tensile stress and elongation was obtained from the result of tensile test. Technical evaluation showed that the rupture stresses of biomass boards were in the range of 4.71MPa to 10.45MPa; and the average values of rupture stress for 5 biomass boards are 6.61MPa, 6.09MPa, 8.01MPa, 5.94MPa, 9.44MPa. The maximum value of rupture stress for 5 biomass board was 10.45MPa under the maximum applied pressure 5MPa. In this study, rupture stresses of the ordinary wrapping paper board used for packaging and polystyrene board used for food pallets were measured, which were 5.05MPa and 6.24MPa.

(4) However, the biomass board is 1.56~3.25 times stronger than the ordinary wrapping paper board, and 1.93~4.02 times stronger than polystyrene board. In addition, the average Young’s Modulus of biomass board is 0.64GPa, which is 2.13 times stronger than the low density polyethylene (LDPE). Consequently,

biomass board can be considered. For applications in agriculture, packaging and building construction.

CHAPTER 3. Effect of Heating Temperature on Mechanical Properties of Biomass Board

3.1 Introduction

Biomass material is biological material derived from renewable raw materials, which is the product of plant photosynthesis with carbon dioxide. In modern history, petroleum and coal are indispensable materials for various industries. However, in the case of creating global environmental problems and increasing depletion, the fossil resources, petroleum and coal, must be replaced in the future. In addition, the supply of timber has been unable to catch up with the need of global economy. It is more and more necessary to develop environment-friendly material. Biomass material is refined as renewable organic material, which is the product of plant photosynthesis with carbon dioxide and after the use it can be degraded into water and carbon dioxide by microbial action or reused as fertilizer through composting.

Crop straw is one kind of crop residues, which are defined as the nonedible plant parts and are left in the field after harvest. Every year, the amount of crop straw is tremendous; however, the availability is rare. The composition of crop straw contains cellulose and hemicellulose which makes straw products have certain physical strength, therefore, the products made of crop straw can replace some products made of wood, petroleum or coal. In addition, after use, it can be degraded into water and carbon dioxide by microbial action or reused as fertilizer through composting, which content the requirement of renewability. Hence, crop straw is considered as an environment-friendly biomass material.

Rice is one of the most important staple food for a large of people in the worldwide. Every year, the yield of rice was the third-highest worldwide production, just after sugarcane and maize. Therefore, at the same time, there were a lot of rice straw are produced. However, as a kind of important biomass material, rice straw has not been effectively utilized. For China as an example, China was the biggest producer in the world, and the yield of rice straw was about 200 million tons. Moreover, 54.8 % of rice straws were burned as fuel, which caused a serious waste of rice straw resource.

Therefore, producing biomass board using rice straw is able to not only replace some products made of wood petroleum or coal but also protect the atmospheric environment. Until the 1940s, the technology which produced the modern building panels made of rice straw appeared. The production technology was pioneered in Sweden in 1930. After World War II, the British made a further development and promotion. The biomass board is rice straw as raw material. After being combed, rice straw was made into board by hot pressing. And then, two pieces of cardboards were pasted on both sides of the board. Currently, there are more than 30 countries in the world to produce the rice straw board and the production capacity is more than 80 million m^3 annually. The board has the disadvantage that: high wastage rate of raw material, poor water proofing property and the requirement of cardboards.

At the end of 1970s, the British invented rice straw particle board. In the 1980s, the rice straw particle board was began to be produced. The production technology was named “Compark Technology” and the he rice straw particle board was named “Compark Board”. Currently, the production technology has been utilized by India, Pakistan, Sri Lanka, Indonesia, Philippines, Australia and other 10 countries. The production method was that: according to the different utilization requirements, different chemical adhesives were added to the rice straw chips, and the mixtures were made into biomass board by hot pressing. The disadvantage of the biomass board was that: because of containing chemical adhesive, the biomass board was not biodegradable and renewable material.

In this study, rice straw that was raw material was used to make biodegradable biomass board. The making processes of biomass board adopt the physical method, which are cutting, soaking, refining, forming and drying. The biomass board made in this study contains no chemical adhesives or chemical compounds. For these reasons, it will not cause any pollution to the environment. In order to investigate material properties of biomass boards, the three-point bending test and tensile test were performed, and rupture stresses of biomass boards were measured.

3.2 Preparation for experimental material

Dry rice straw was used as raw material in this study. First of all, dry rice straw was cut into chips about 15mm. Then, the chips were soaked in water for 96 hours at room temperature. This process was very important to make biomass board successfully. During the process, the fiber of rice straw expanded in water, and some organic and inorganic substance dissolved in water. That is because, the microorganisms on rice straw began to ferment. Some chemical compositions which are disadvantageous to the strength of biomass board will be removed by the soaking process such as lignin, pectin, and so on. In this study, 5 biomass boards named A, B, C, D, E were made by the same maximum applied pressure 5MPa and different temperature in the process of forming and drying. 5 levels of the heating temperatures 110^{o}C, 130^{o}C, 150^{o}C, 170^{o}C and 190^{o}C were applied on biomass boards. Table 1 shows the experimental condition for making biomass board in this study.

Table 3-1 shows the experimental conditions for making biomass board using rice straw in this study.

Table 3- 1 Experimental conditions for making biomass board

No.	Soaking	Refining	Forming and drying		
	Time/h	Time/min	Maximum Pressure/MPa	Temperature/℃	Time/h
A	96	10	5.0	110	2
B	96	10	5.0	130	2
C	96	10	5.0	150	2
D	96	10	5.0	170	2
E	96	10	5.0	190	2

3.3 Biomass board making process

After soaking, the mixture of rice straw chips and water was refined into rice straw pulp by an electric beating refiner for 10 minutes, so that the fibers of rice straw were separated into individual fibers using the electric beating refiner and the fiber whose length was under 5.6mm was sieved from rice straw pulp for making biomass board. During this process, the macromolecular fibers were refined into microfibers and more active hydroxyl groups were exposed, which were conducive to forming. The final making process was forming and drying. The schematic diagram of forming process was shown in Fig.3-2. The dimension of the forming mold was 100mm×100mm×25mm. In addition, some accessories were necessary for mold, which were two metal meshes, a copper block and an aluminum plate. In order to drain off water from rice straw pulp during this process, the forming mold, the copper block and the aluminum plate were drilled holes which were 2mm in diameter with an interval of 7mm×7mm. Pressure was applied gradually for 2 hours.

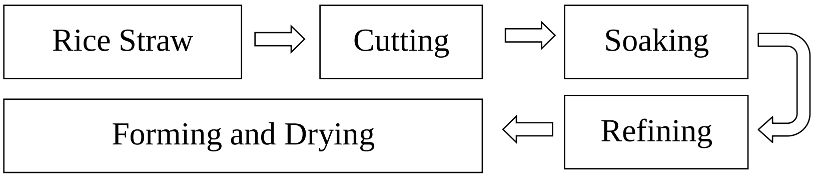


Fig.3- 1 The process of making biomass board

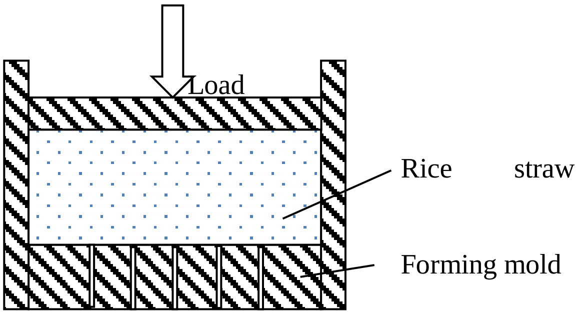


Fig.3- 2 The schematic diagram of forming process

In this study, 5 biomass boards named A, B, C, D, E were made by the same maximum applied pressure 5MPa and different temperature in the process of forming and drying. 5 levels of the heating temperatures 110^{o}C, 130^{o}C, 150^{o}C, 170^{o}C and 190^{o}C were applied on biomass boards. Table 1 shows the experimental condition for making biomass board in this study.

3.4 Measurement of density and moisture content

After the biomass boards were made successfully, the sizes of them were measured for density. The measurement method was the same as Chapter 2. We can get L1, L2, L3 for length, D1, D2, D3 for width, H1, H2, H3, H4, H5, H6, H7, H8 for thickness.

Because the moisture content of biomass board in this study is an important physical parameter of bio-based materials, in this study, the moisture content of every biomass board also was measured. The calculation method of the moisture content was by Equation (2.1) as the same as Chapter 2.

3.5 Strength stress

The rice straw biomass boards were complex non-homogeneous materials so that the mechanical properties of biomass boards must be examined carefully. In order to investigate mechanical properties of the biomass boards, the three-point bending test and tensile test were carried out in this study. The universal material testing machine was used for the two tests. Two specimens were cut for bending test and three specimens were cut for tensile test from every biomass board.

The specimens for three-point bending test were rectangle with dimensions of 50mm×40mm. In this. Both ends of specimens were supported, and force was loaded at the center of the specimens until fracture. Stress (σ) was obtained by the results of the bending test to confirm the mechanical properties of the biomass boards.. It collected electrical signals in the test and changed them into load (N) and deflection (mm). The rupture stress was calculated by Equation (2.2) as the same as Chapter 2.

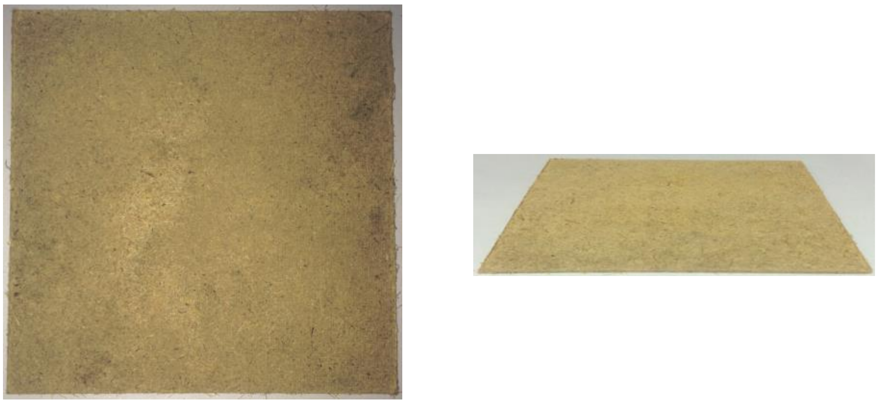
The dimensions of specimens for tensile test were shown in Fig.2-13 as the same as Chapter 2. The universal testing machine was used for measuring load (N) and elongation (mm). Tensile stress σ_b was obtained by the results of the tensile test. The stress was calculated by Equation. (2.3) as the same as Chapter 2.

3.6 Results and discussions

3.6.1 Results of making biomass board

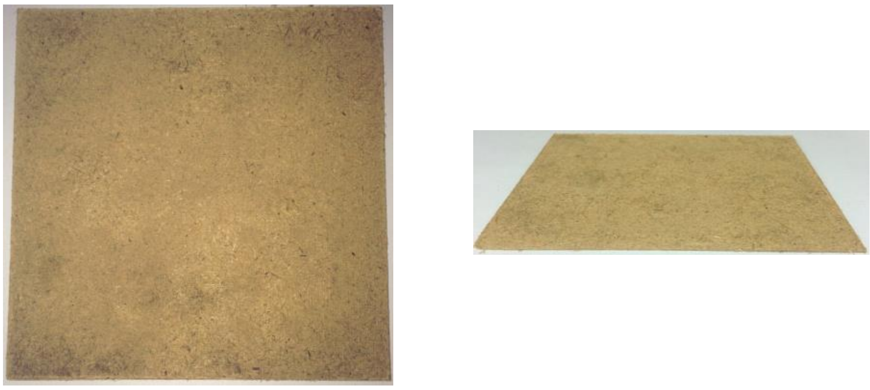
In this study, rice straw was used to make biomass boards. Cutting, soaking, refining, forming and drying were carried out to complete the biomass boards. 5 pieces of biomass boards were made at different maximum applied pressures. Making 5 pieces of biomass boards named Board A, Board B, Board C, Board D, Board E was successful at every experimental condition proposed in this study. The result of the experiment indicates that the processes of cutting, soaking, refining, forming and drying are appropriate for making biomass boards using rice straw. Fig.3-3 shows the biomass boards.

a. biomass board A (heating temperature was 110℃)

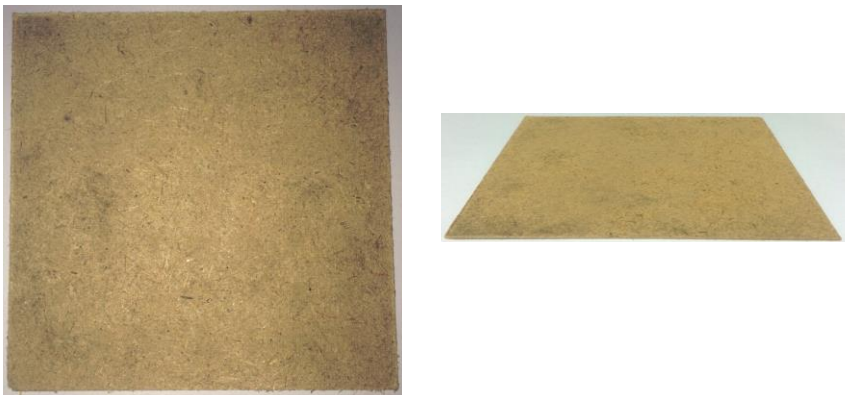


b. biomass board B (heating temperature was 130℃)

c. biomass board C (heating temperature was 150℃)



d. biomass board D (heating temperature was 170℃)



e. biomass board E (heating temperature was 190℃)

Fig.3- 3 The biomass boards were made of 5 kinds of applied pressures

3.6.2 Results of moisture content and density

According to the measurement method of Fig.2-13, the dimensions of biomass boards were shown in Table 3-2.

Table 3- 2 The dimension of biomass boards

(a)

Board A	1	2	3	4	5	6	7	8	Ave.
L/mm	100.05	100.05	100.10						
D/mm	100.10	100.10	100.10						
H/mm	1.080	0.935	0.980	1.035	0.990	0.965	0.770	0.914	1.164
Mass/g									8.40
Density/ 10^3kg/m^3									0.826

(b)

Board B	1	2	3	4	5	6	7	8	Ave.
L/mm	100.10	100.10	100.10						100.10
D/mm	100.10	100.15	100.15						100.13
H/mm	0.878	0.848	0.910	0.868	0.960	0.961	0.930	0.850	0.901
Mass/g									7.45
Density/ 10^6kg/m^3									0.859

(c)

Board C	1	2	3	4	5	6	7	8	Ave.
L/mm	100.20	100.25	100.20						100.21

D/mm	100.20	100.20	100.20						100.20
H/mm	0.867	0.940	0.907	0.795	0.742	0.835	0.915	0.760	1.502
Mass/g									6.98
Density/ $10^6 kg/m^3$									0.859

(d)

Board D	1	2	3	4	5	6	7	8	Ave.
L/mm	100.20	100.25	100.20						100.22
D/mm	100.20	100.20	100.20						100.20
H/mm	0.868	0.810	0.895	0.825	0.844	0.892	0.928	0.830	0.862
Mass/g									6.91
Density/ $10^6 kg/m^3$									0.875

(e)

Board E	1	2	3	4	5	6	7	8	Ave.
L/mm	100.25	100.25	100.25						100.25
D/mm	100.25	100.20	100.20						100.22
H/mm	1.055	0.984	1.155	0.995	0.949	0.884	0.975	1.000	1.000
Mass/g									8.69
Density/ $10^6 kg/m^3$									0.909

According to the dimensions of biomass boards, moisture content and the density of biomass board were measured. In this study, moisture content was relative water content. Fig.3-3 shows the values of moisture content and density of biomass board. The moisture content was in the range of 3.78%~7.00% and the average was 5.01%. The density was in the range of 0.83×10^3kg/m^3~0.91×10^3kg/m^3 and the average was 0.87×10^3kg/m^3.

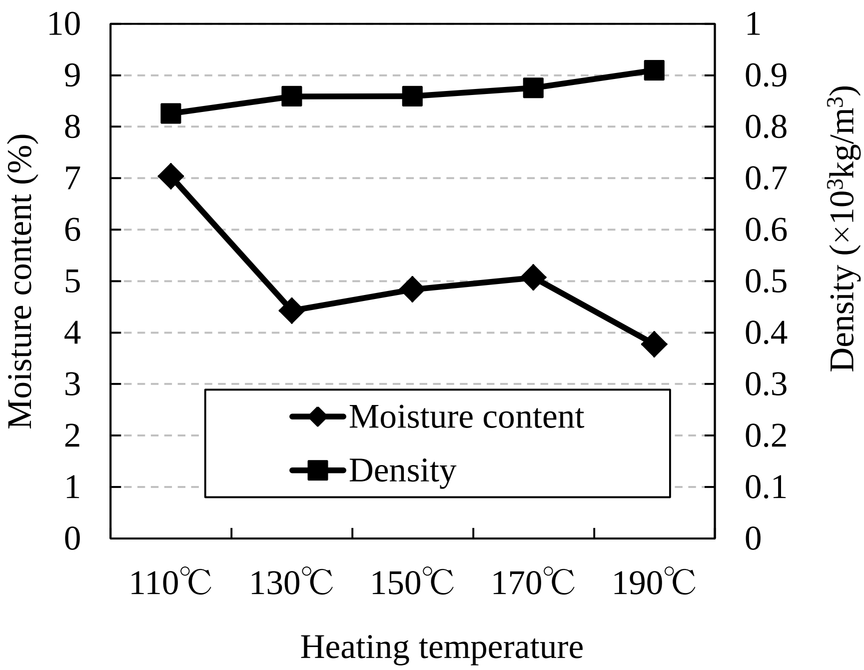


Fig.3- 4 Moisture content and density of biomass board

3.6.3 Results of three-points bending test

2 specimens for bending test were cut from every biomass board respectively. The 2 specimens were named S1 and S2 from every biomass board made under different heating temperatures. The relationships between stress and deflection of 5 biomass boards are shown in from Fig.3-4.

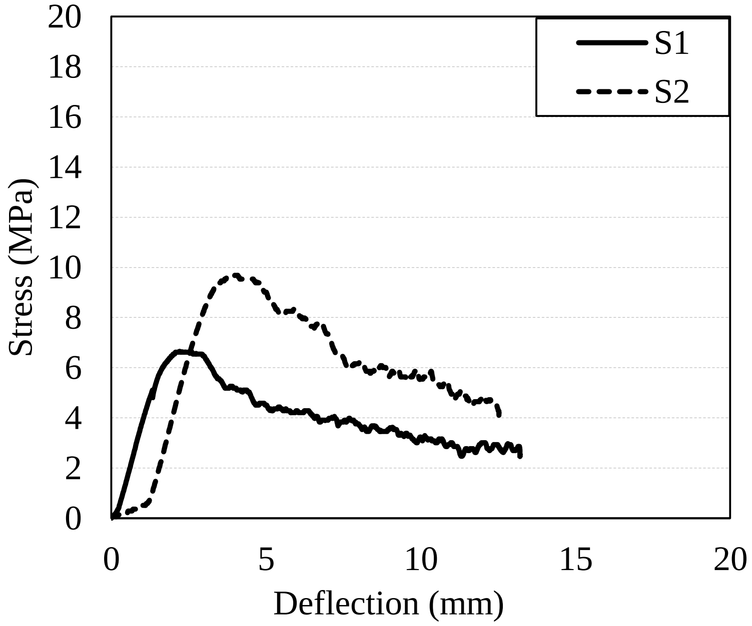
From biomass board A, according to the curve of stress-deflection, for the 2 specimens, the stress increased with the increase of deflection until the stress reached maximum value. At the time, specimens fractured. And then, the stress decreased to zero gradually. The maximum value of stress was named as rupture stress. Rupture stresses of the 2 specimens were 13.57MPa and 14.77MPa.

From biomass board B, according to the curve of stress-deflection, for the 2 specimens, the stress increased with the increase of deflection until the stress reached maximum value. At the time, specimens fractured. And then, the stress decreased to zero gradually. The maximum value of stress was named as rupture stress. Rupture stresses of the 2 specimens were 13.54MPa and 14.99MPa.

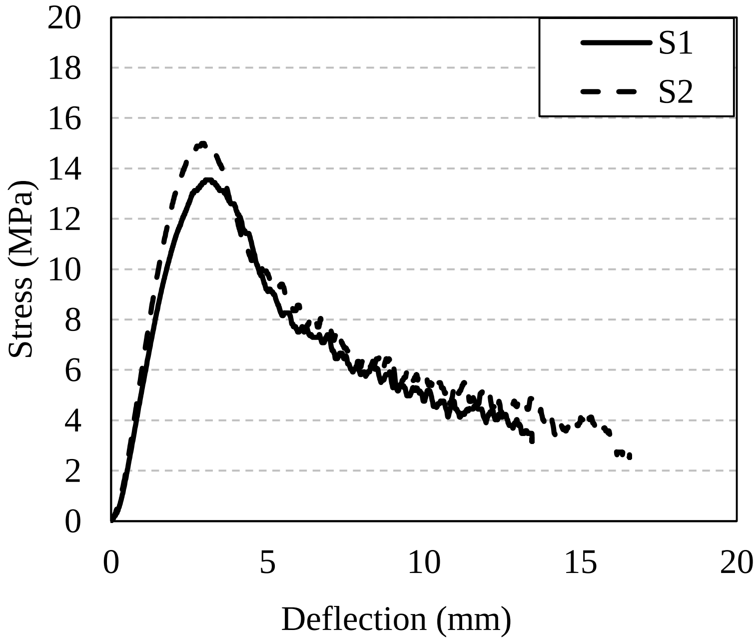
From biomass board C, according to the curve of stress-deflection, for the 2 specimens, the stress increased with the increase of deflection until the stress reached maximum value. At the time, specimens fractured. And then, the stress decreased to zero gradually. The maximum value of stress was named as rupture stress. Rupture stresses of the 2 specimens were 13.35MPa and 16.77MPa.

From biomass board D, according to the curve of stress-deflection, for the 2 specimens, the stress increased with the increase of deflection until the stress reached maximum value. At the time, specimens fractured. And then, the stress decreased to zero gradually. The maximum value of stress was named as rupture stress. Rupture stresses of the 2 specimens were 19.62MPa and 13.75MPa.

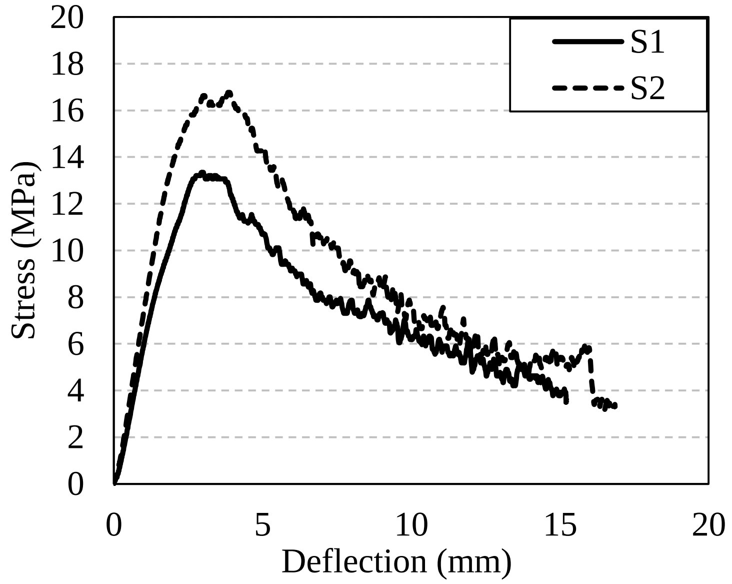
From biomass board E, according to the curve of stress-deflection, for the 2 specimens, the stress increased with the increase of deflection until the stress reached maximum value. At the time, specimens fractured. And then, the stress decreased to zero gradually. The maximum value of stress was named as rupture stress. Rupture stresses of the 2 specimens were 19.59MPa and 17.40MPa.



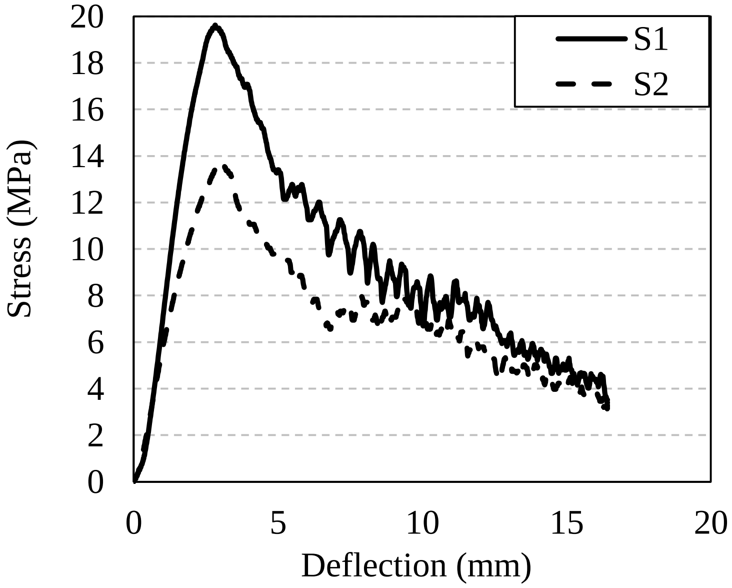
a. The stress-deflection curve of biomass board A



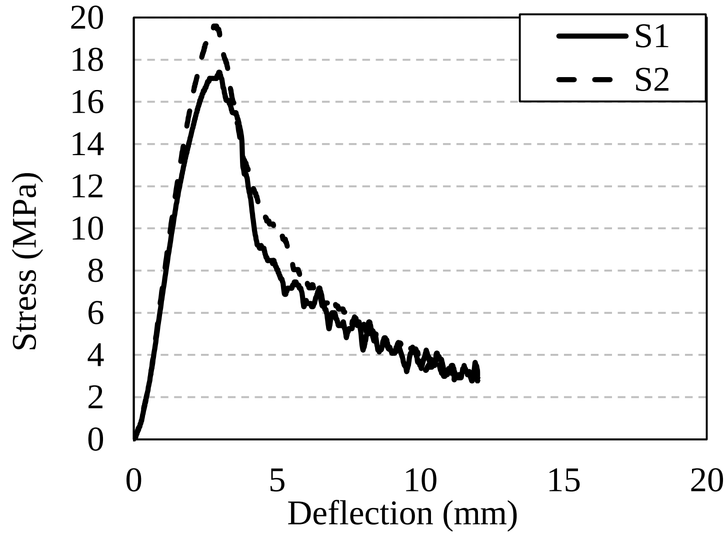
b. The stress-deflection curve of biomass board B



c. The stress-deflection curve of biomass board C



d. The stress-deflection curve of biomass board D



e. The stress-deflection curve of biomass board E

Fig.3- 5 The stress-deflection curves of 5 biomass boards

Rupture stress comparison is showed in Fig.3-5. The rupture stresses were in the range of 13.35MPa~19.62MPa, and the average values of 5 biomass boards are 14.17MPa, 14.27MPa, 15.06MPa, 16.68MPa, 18.50MPa respectively. At heating temperature of 190℃, the average value of rupture stress is maximum, which is 18.50MPa.

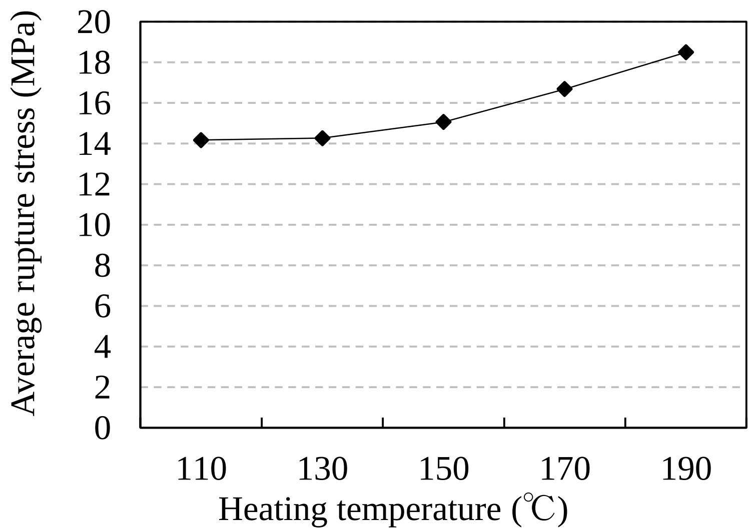
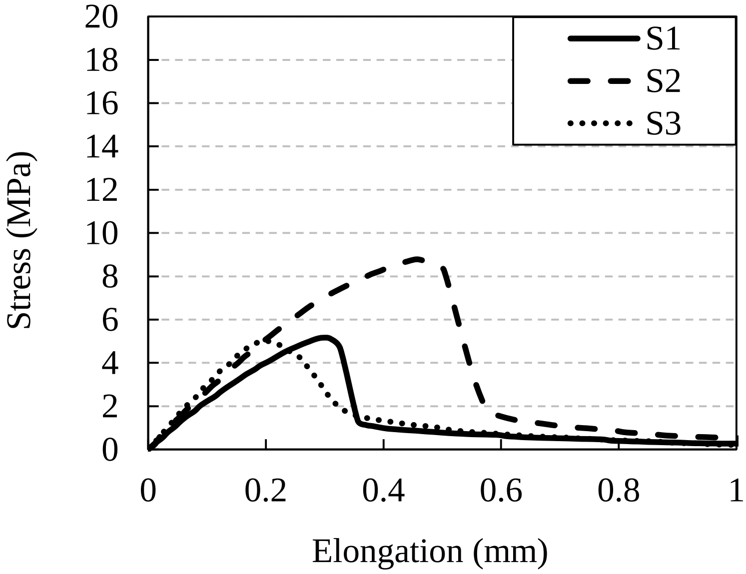


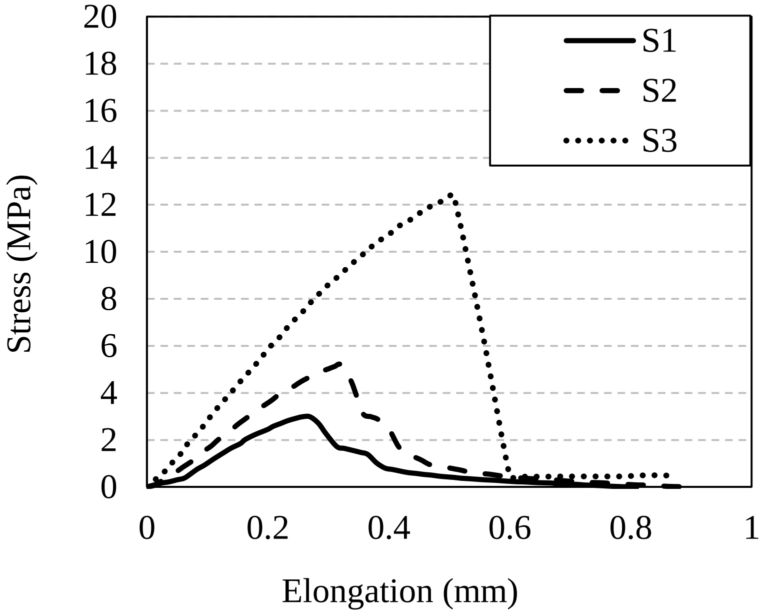
Fig.3- 6 The average rupture stress of biomass board

3.6.4 Results of tensile test

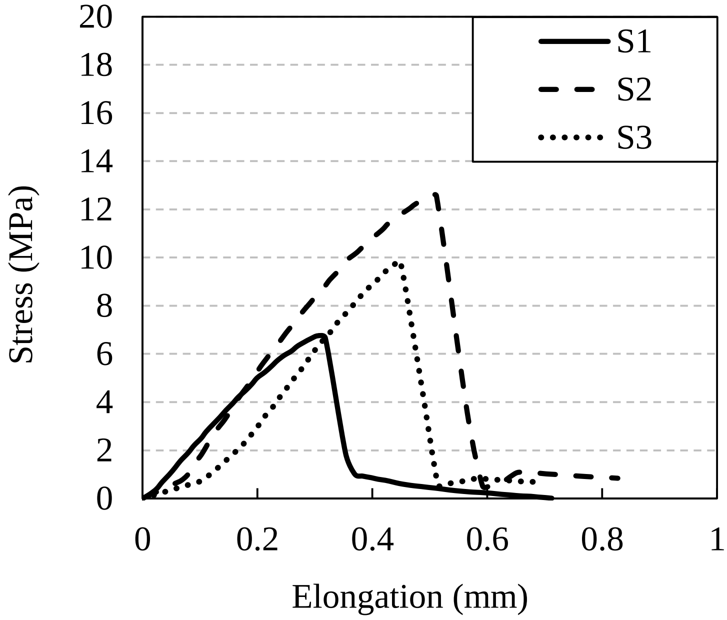
In tensile test, 3 specimens for tensile test were cut from every biomass board respectively. The 3 specimens were named S1, S2 and S3 from every biomass board made under different heating temperatures. Tensile test was carried out. The results is showed in Fig.3-6.



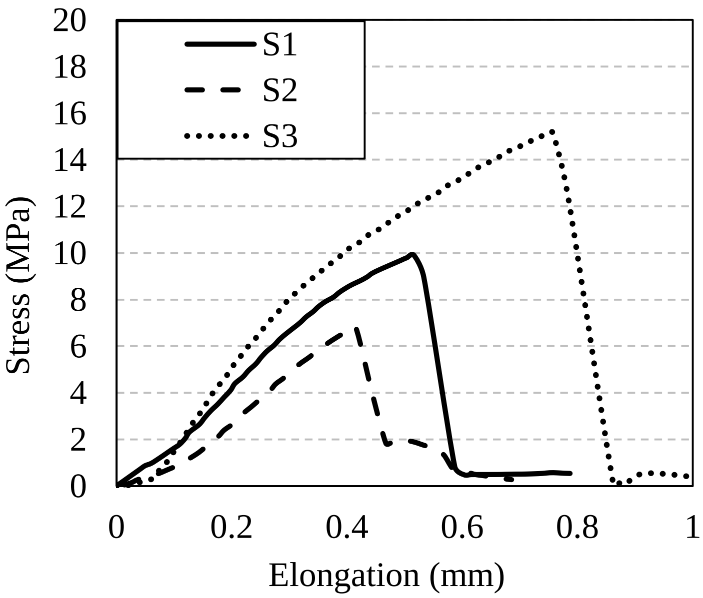
a. The stress-elongation curve of biomass board A



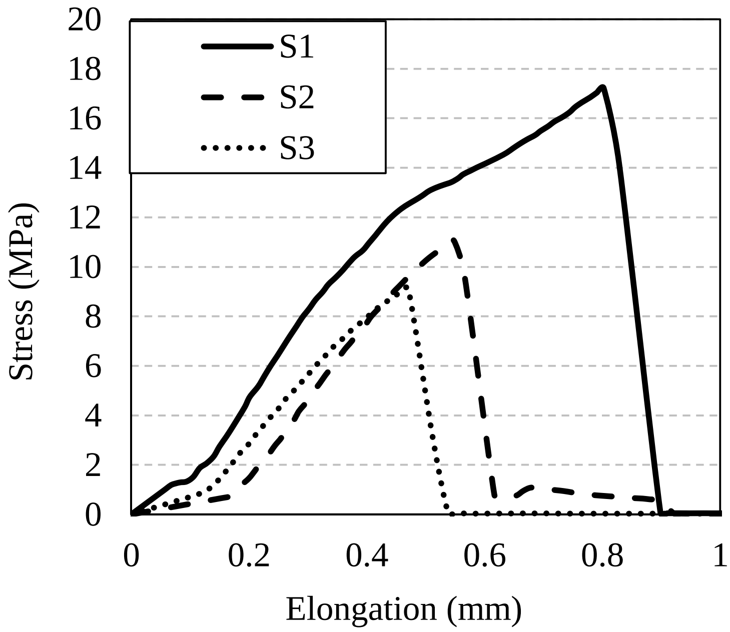
b. The stress-elongation curve of biomass board B



c. The stress-elongation curve of biomass board C



d. The stress-elongation curve of biomass board D



e. The stress-elongation curve of biomass board E

Fig.3- 7 The stress-elongation curve of biomass board

From biomass board A, the stress increased with the increase of elongation. When the specimen was fractured, the stress reached a maximum value also named as rupture stress. Subsequently, the stress was back to zero rapidly. Rupture stresses of the 3 specimens were 3.35MPa, 5.01MPa and 7.38MPa.

From biomass board B, the stress increased with the increase of elongation. When the specimen was fractured, the stress reached a maximum value also named as rupture stress. Subsequently, the stress was back to zero rapidly. Rupture stresses of the 3 specimens were 2.99MPa,5.19MPa and 12.39MPa.

From biomass board C, the stress increased with the increase of elongation. When the specimen was fractured, the stress reached a maximum value also named as rupture stress. Subsequently, the stress was back to zero rapidly. Rupture stresses of the 3 specimens were 6.75MPa, 12.56MPa and 9.82MPa.

From biomass board D, the stress increased with the increase of elongation. When the specimen was fractured, the stress reached a maximum value also named as rupture stress. Subsequently, the stress was back to zero rapidly. Rupture stresses of the 3 specimens were 9.90MPa, 6.80MPa and15.15MPa.

From biomass board E, the stress increased with the increase of elongation. When the specimen was fractured, the stress reached a maximum value also named as rupture stress. Subsequently, the stress was back to zero rapidly. Rupture stresses of the 3 specimens were 17.22MPa, 11.05MPa and 9.13MPa.

Rupture stress comparison is showed in Fig.3-7. The rupture stresses of tensile test were in the range of 3.00MPa~17.22MPa and the average values of 5 biomass boards are 5.25MPa, 6.86MPa, 9.71MPa, 10.62MPa, 12.46MPa. At heating temperature of 190^{o}C, the average value of rupture stress is maximum, which is 12.46MPa.

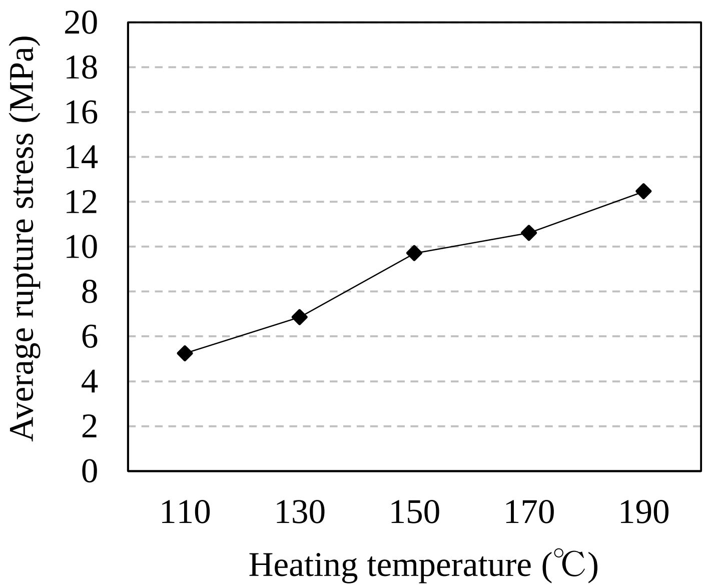


Fig.3- 8 The average rupture stress of biomass board

3.7 Conclusions

The main objective of this study was to investigate the possibility of making biodegradable biomass board using rice straw and the relationship between heating temperature and mechanical properties of it. 5 pieces of biomass boards were made by the processes of cutting, soaking, refining, forming and drying with the experimental condition of the maximum applied pressure 5MPa, temperatures 110℃, 130℃, 150℃, 170℃ and 190℃. Mechanical properties of the biomass boards were investigated by three-point bending test and tensile test. It can be concluded as follows:

1) According to the result of this study, the rice straw biomass board was made successfully using the proposal method. The making process including cutting, soaking, refining, forming and drying was appropriate. In addition, no chemical adhesives or chemical compounds were added in whole making process of biomass board. The biomass board made in this study is biodegradable, and is an environment-friendly material.

2) In the three-point bending test, it showed that the rupture stresses were in the range of 13.35MPa~ 19.62MPa. The average of maximum rupture stress appears at heating temperature of 190℃ which is 18.50MPa. And in the tensile test, the result showed that the rupture stresses were in the range of 3.00MPa~17.22MPa. The average of maximum rupture stress was 12.46MPa at heating temperature 190o℃. The results indicated that heating temperature affected the strength of biomass board. The rupture stress increased with the increase of heating temperature.

3) Consequently, according to the mechanical properties of biomass board, it can be considered for applications in agriculture, packaging and building construction.

CHAPTER 4. Effect of Refining on Mechanical Properties of Biomass Board

4.1 Introduction

This study will explore to improve the strength of biomass board for various utilization. In chapter 2 and chapter 3, the effects of applied pressure and heating temperature in forming and drying process on the strength of biomass board were investigated. However, the results indicated that the strength of biomass board was not significantly influenced by different pressures applied during the forming and drying process. In addition, biomass board is composite, hence, its strength is affected by numerous uncertain factors. According to previous research on biomass board making, many factors affect the strength of biomass board such as pressure, temperature, moisture content, length of fiber and so on.

The goal of this study was also to make biodegradable biomass board from rice straw without any chemical adhesives or chemical compounds in the making process. To explore the effect of different fiber length on mechanical properties of biomass board was investigated. After refining, the rice straw pulp was in divided into 3 kinds by the fiber length . With fiber length as a variable, 15 pieces of biomass boards were made. And then, the mechanical property of biomass board was also investigated. Finally, from this study, the effect factor of fiber length would be made sure.

4.2 Preparation for experimental material

Dry rice straw was used as raw material in this study. First of all, dry rice straw was cut into chips about 15mm. Then, the chips were soaked in water for 96 hours at room temperature. This process was very important to make biomass board successfully. During the process, the fiber of rice straw expanded in water, and some organic and inorganic substance dissolved in water. That is because, the microorganisms on rice straw began to ferment. Some chemical compositions which are disadvantageous to the strength of biomass board will be removed by the soaking process such as lignin, pectin, and so on. In this study, in order to investigate the effect the refining degree on strength of biomass board, fibers were divided into three degrees by length which named SF, MF, LF. Table 4-1 shows the experimental condition for making biomass board in this study.

4.3 Biomass board making process

After soaking, the mixture of rice straw chips and water was refined into rice straw pulp by an electric beating refiner for 10 minutes, so that the fibers of rice straw were separated into individual fibers using the electric beating refiner and the fiber whose length was under 5.6mm was sieved from rice straw pulp for making biomass board. During this process, the macromolecular fibers were refined into microfibers and more active hydroxyl groups were exposed, which were conducive to forming. After refining, the rice straw pulp was in divided into 3 kinds by the fiber length . The range of three degrees of fiber length was 0mm<SF≤2.0mm, 2.0mm<MF≤4.0mm, 4.0mm<LF≤5.6mm. The final making process was forming and drying. The schematic diagram of forming process was shown in Fig.4-1. The dimension of the forming mold was 100mm×100mm×25mm. In addition, some accessories were necessary for mold, which were two metal meshes, a copper block and an aluminum plate. In order to drain off water from rice straw pulp during this process, the forming mold, the copper block and the aluminum plate were drilled holes which were

2mm in diameter with an interval of 7mm×7mm. Pressure was applied gradually for 2 hours.

Table 4- 1 Experimental conditions for making biomass board

Fiber length	Soaking	Refining	Forming and drying		
	Time/h	Time/min	Maximum Pressure/MPa	Temperature/℃	Time/h
			2.0		
LF			3.5		
MF	96	10	5.0	110	2
SF			6.5		
			8.0		

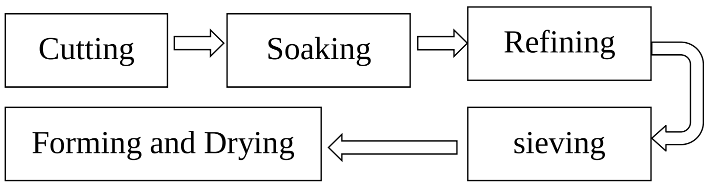


Fig.4- 1 The process for making biomass board

In this study, 15 biomass boards were made. 5 pieces biomass boards which was made by the same fiber length was one group. Every 5 biomass boards in the same group is made by the same heating temperature 110°C and different applied pressures 2.0MPa, 3.5MPa, 5.0MPa, 6.5MPa, 8.0MPa. The biomass boards in LF group were named LF-1, LF- 2, LF- 3, LF-4, LF-5; The biomass boards in MF group were named MF-1, MF-2, MF-3, MF-4, MF-5; The biomass boards in SF group were named SF-1, SF-2, SF-3, SF-4, SF-5.

4.4 Measurement of density and moisture content

After the biomass boards were made successfully, the sizes of them were measured for density. The measurement method was the same as Chapter 2. We can get L1, L2, L3 for length, D1, D2, D3 for width, H1, H2, H3, H4, H5, H6, H7, H8 for thickness.

Because the moisture content of biomass board in this study is an important physical parameter of bio-based materials, in this study, the moisture content of every biomass board also was measured. The calculation method of the moisture content was by Equation (2.1) as same as Chapter.

4.5 Strength stress

The rice straw biomass boards were complex non-homogeneous materials so that the mechanical properties of biomass boards must be examined carefully. In order to investigate mechanical properties of the biomass boards, the three-point bending test and tensile test were carried out in this study. The universal material testing machine was used for the two tests. Two specimens were cut for bending test and three specimens were cut for tensile test from every biomass board.

The specimens for three-point bending test were rectangle with dimensions of 50mm×40mm. In this. Both ends of specimens were supported, and force was loaded at the center of the specimens until fracture. Stress (σ) was obtained by the results of the bending test to confirm the mechanical properties of the biomass boards. It collected electrical signals in the test and changed them into load (N) and deflection (mm). The rupture stress was calculated by Equation (2.2) as same as Chapter 2.

The dimensions of specimens for tensile test were shown in Fig.2-13 as the same as Chapter 2. The universal testing machine was used for measuring load (N) and elongation (mm). Tensile stress σ_b was obtained by results of the tensile test. The stress was calculated by Equation. (2.3) as same as Chapter 2.

4.6 Results and discussions

4.6.1 Results of making biomass board

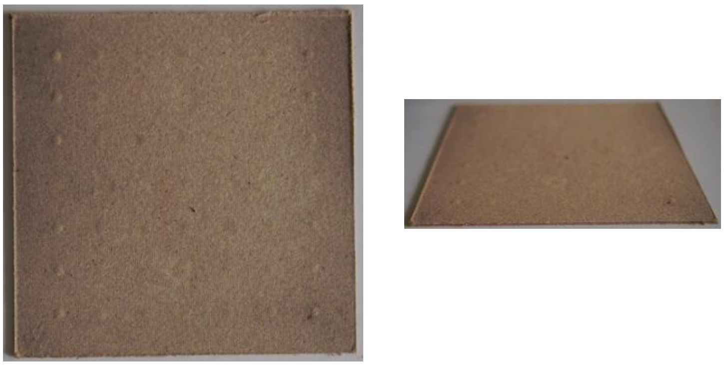
In this study, rice straw was used to make biomass boards. Cutting, soaking, refining, sieving, forming and drying were carried out to complete the biomass boards. 15 pieces of biomass boards were made at different conditions. The result of the experiment indicates that the processes of cutting, soaking, refining, sieving, forming and drying are appropriate for making biomass boards using rice straw. Fig.4-2 shows the biomass boards.

biomass board SF-1: 0mm < fiber length ≤2.0mm, applied pressure was 2.0MPa

biomass board SF-2: 0mm < fiber length ≤2.0mm, applied pressure was 3.5MPa

biomass board SF-3: 0mm < fiber length ≤2.0mm, applied pressure was 5.0MPa

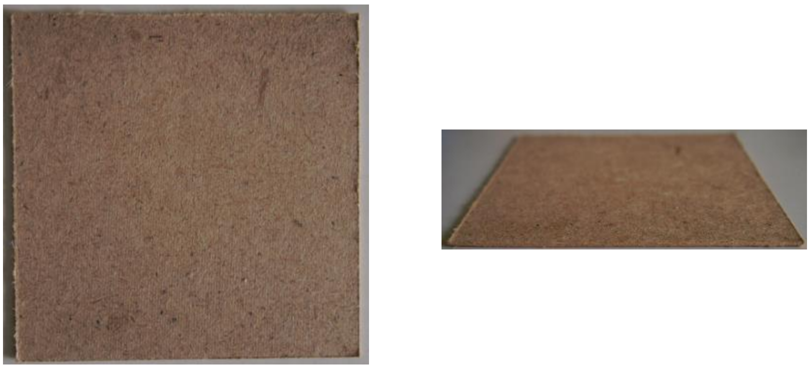
biomass board SF-4: 0mm < fiber length ≤2.0mm, applied pressure was 6.5MPa



biomass board SF-5: 0mm < fiber length ≤2.0mm, applied pressure was 8.0MPa

biomass board MF-1: 2mm < fiber length ≤4.0mm, applied pressure was 2.0MPa

biomass board MF-2: 2mm < fiber length ≤4.0mm, applied pressure was 3.5MPa

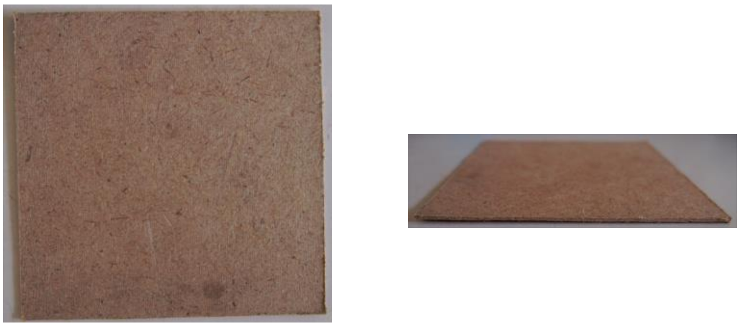


biomass board MF-3: 2mm < fiber length ≤4.0mm, applied pressure was 5.0MPa

biomass board MF-4: 2mm < fiber length ≤4.0mm, applied pressure was 6.5MPa

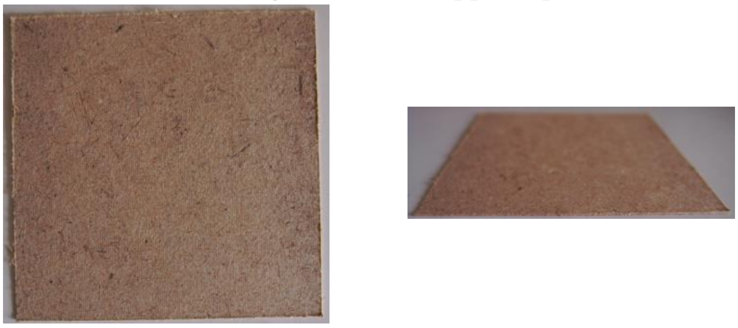
biomass board MF-5: 2mm < fiber length ≤4.0mm, applied pressure was 8.0MPa

biomass board LF-1: 4mm < fiber length ≤5.6mm, applied pressure was 2.0MPa

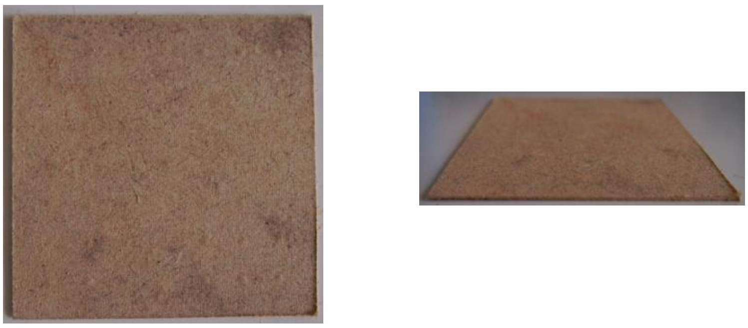


biomass board LF-2: 4mm < fiber length ≤5.6mm, applied pressure was 3.5MPa

biomass board LF-3: 4mm < fiber length ≤5.6mm, applied pressure was 5.0MPa



biomass board LF-4: 4mm < fiber length ≤5.6mm, applied pressure was 6.5MPa



biomass board LF-5: 4mm < fiber length ≤5.6mm, applied pressure was 8.0MPa

Fig.4- 2 The biomass boards were made of 3 kinds of fiber length

4.6.2 Results of three-point bending test

4 specimens for bending test were cut from every biomass board respectively. The 4 specimens were named S1, S2, S3 and S4 from every biomass board. The relationships between stress and deflection of 15 biomass boards are shown in from Fig.4-3.

From biomass board SF-1, according to the curve of stress-deflection, for the 4 specimens, the stress increased with the increase of deflection until the stress reached maximum value. At the time, specimens fractured. And then, the stress decreased to zero gradually. The maximum value of stress was named as rupture stress. Rupture stresses of the 4 specimens were 27.90MPa, 30.82MPa, 32.10MPa and 26.46MPa which were shown in from Fig.4-3(a).

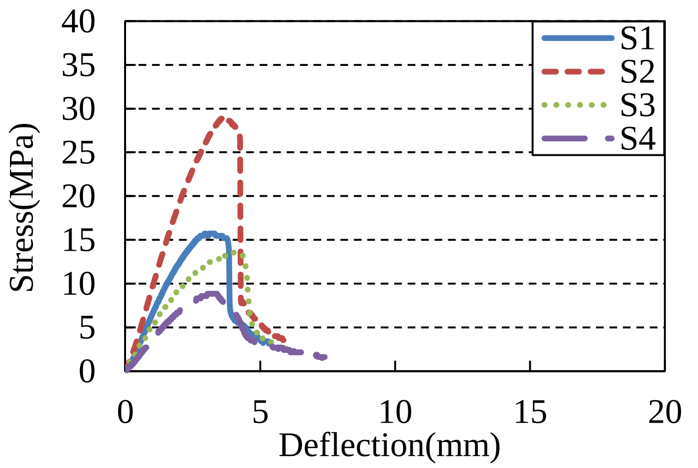
The stress-deflection curves of specimens cut from the other 14 bio-boards were similar to the biomass board SF-1, which were shown in from Fig.4-3(b) to Fig.4-3(o). The relationship of stress-deflection for every specimen from one biomass board was similar while the rupture stresses were different from each other. The rupture stresses of biomass board SF-2 were 28.08MPa, 32.59MPa, 30.72MPa, 24.46MPa.

The rupture stresses of biomass board SF-3 were 15.73MPa, 29.06MPa, 13.55MPa, 8.85MPa.

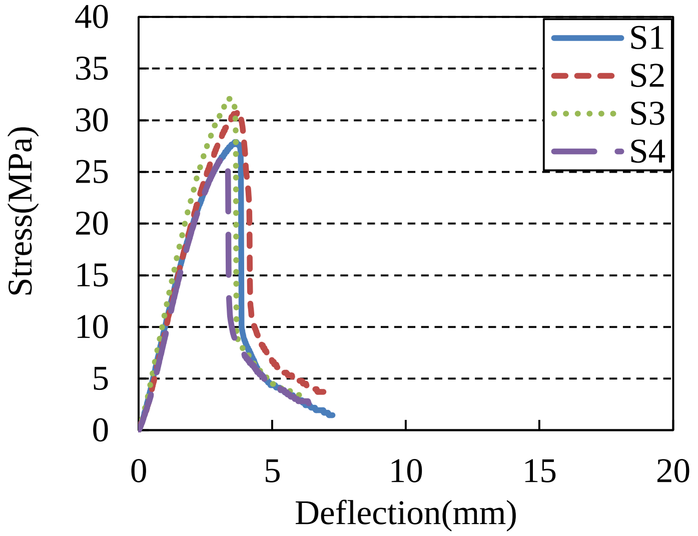
The rupture stresses of biomass board SF-4 were 32.17 MPa, 27.24 MPa, 19.85 MPa, 35.97MPa.

The rupture stresses of biomass board SF-5 were 24.22MPa, 30.80MPa, 32.36MPa, 15.56MPa.

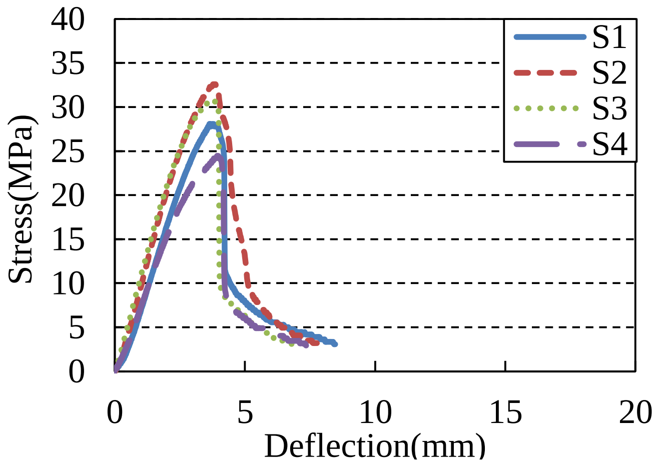
Average rupture stress comparison is showed in Fig.4-4.The maximum ruptures stress 19.71 MPa appeared in biomass board SF-3 whose fiber length was between 0-2mm and max pressure was 5MPa.



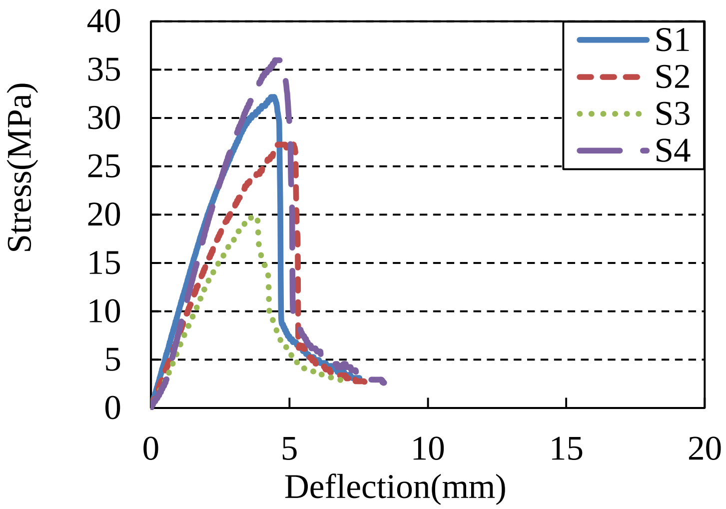
a. The stress-deflection curve of biomass board SF-1



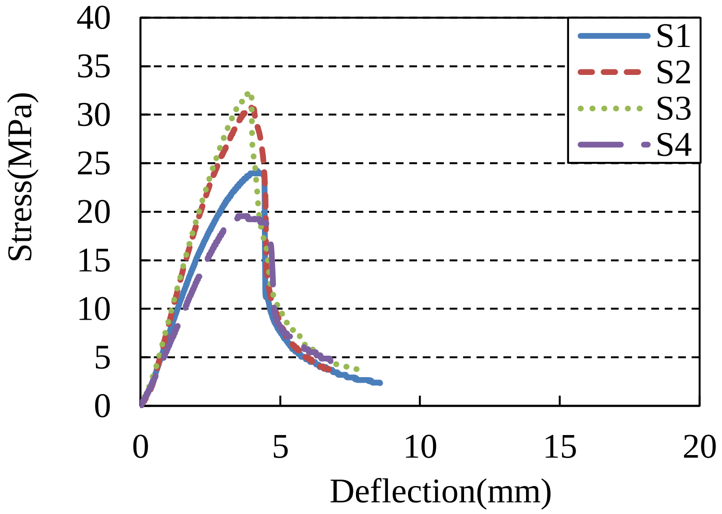
b. The stress-deflection curve of biomass board SF-2



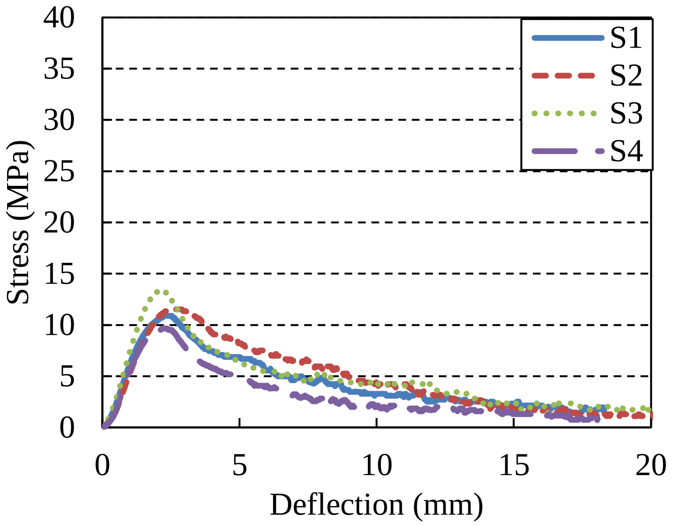
c. The stress-deflection curve of biomass board SF-3



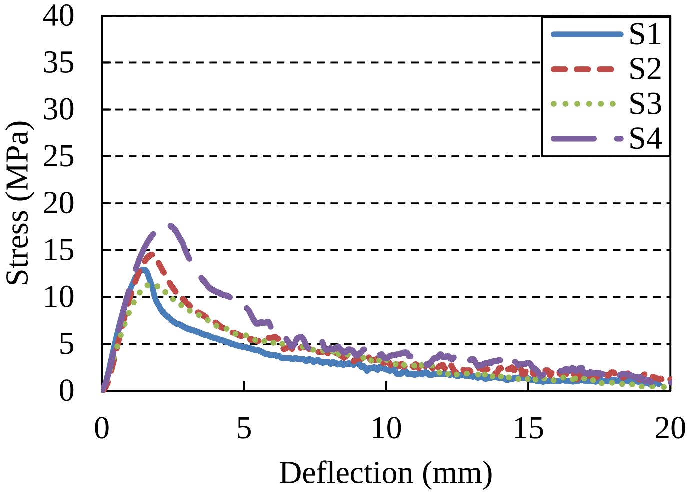
d. The stress-deflection curve of biomass board SF-4



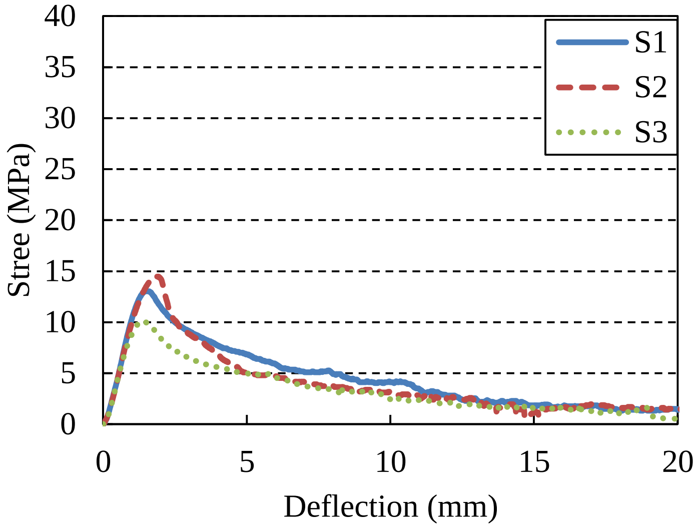
e. The stress-deflection curve of biomass board SF-5



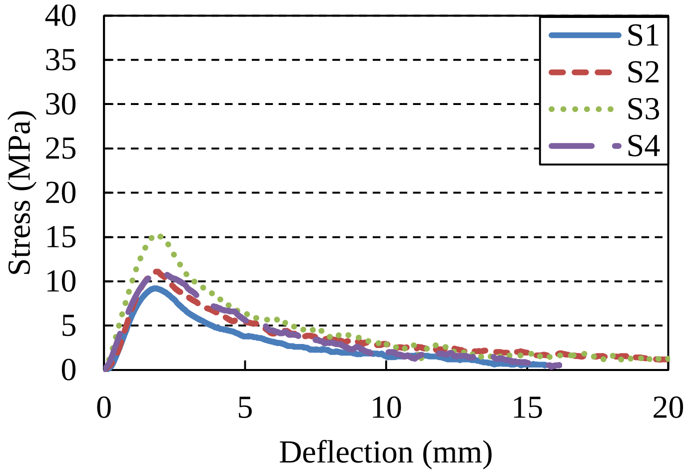
f. The stress-deflection curve of biomass board MF-1



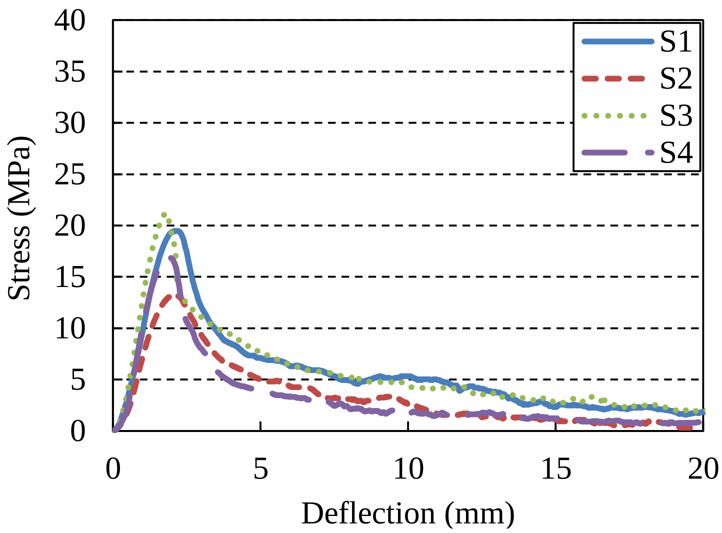
g. The stress-deflection curve of biomass board MF-2



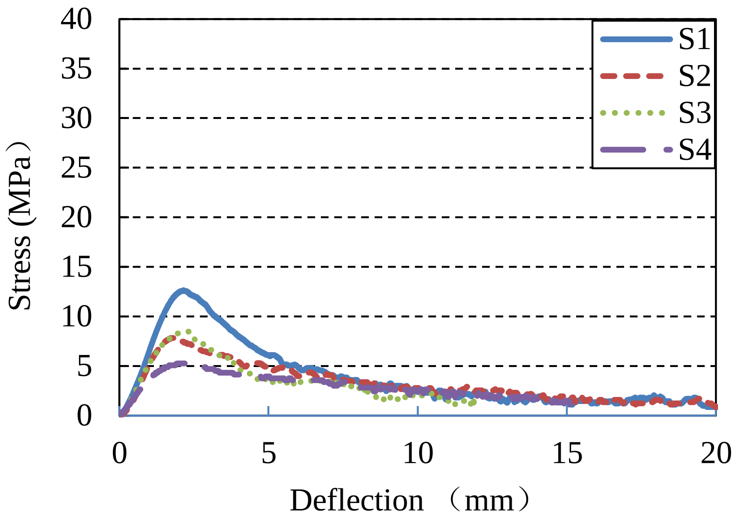
h. The stress-deflection curve of biomass board MF-3



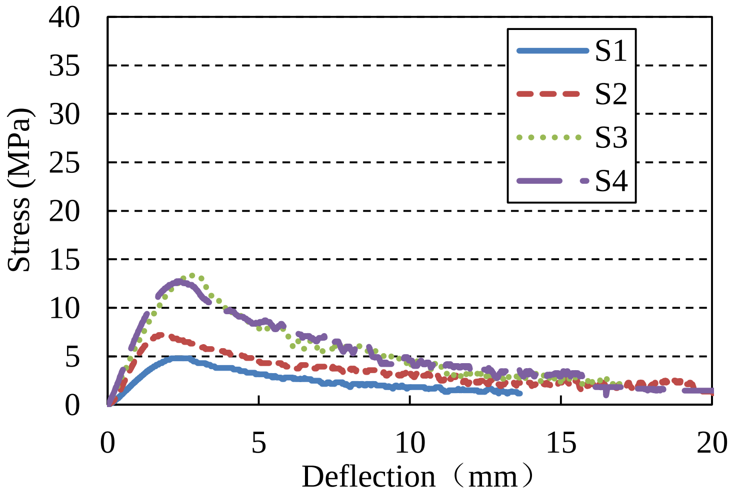
i. The stress-deflection curve of biomass board MF-4



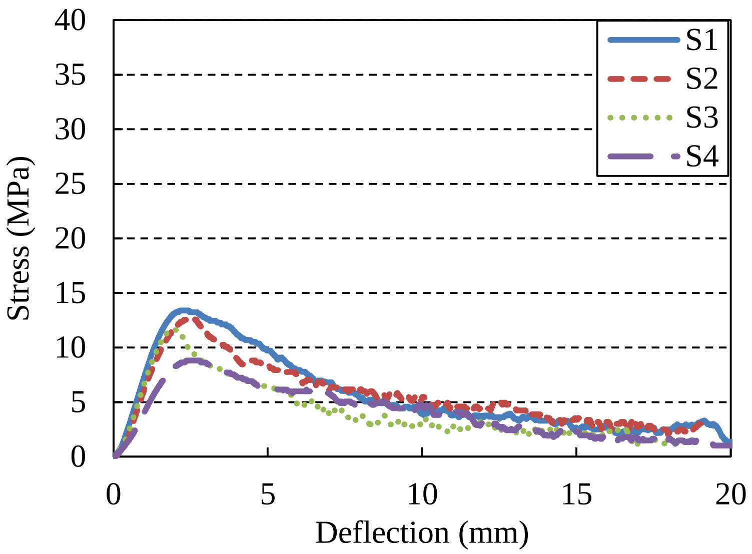
j. The stress-deflection curve of biomass board MF-5



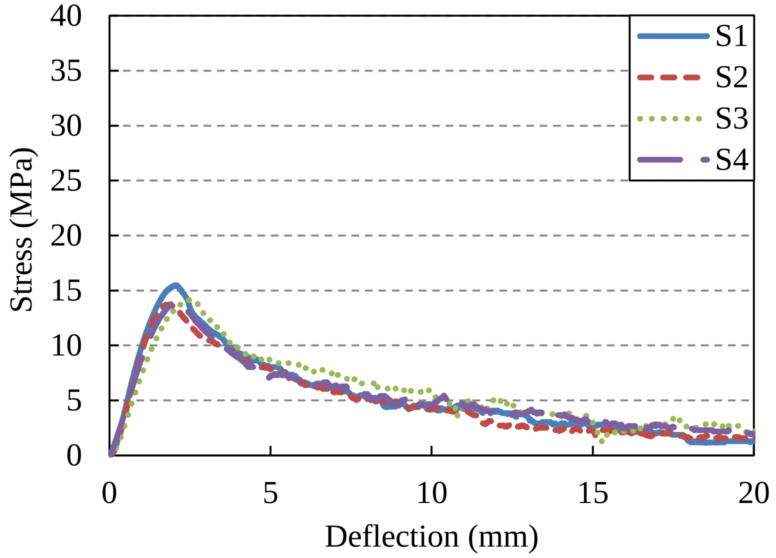
k. The stress-deflection curve of biomass board LF-1



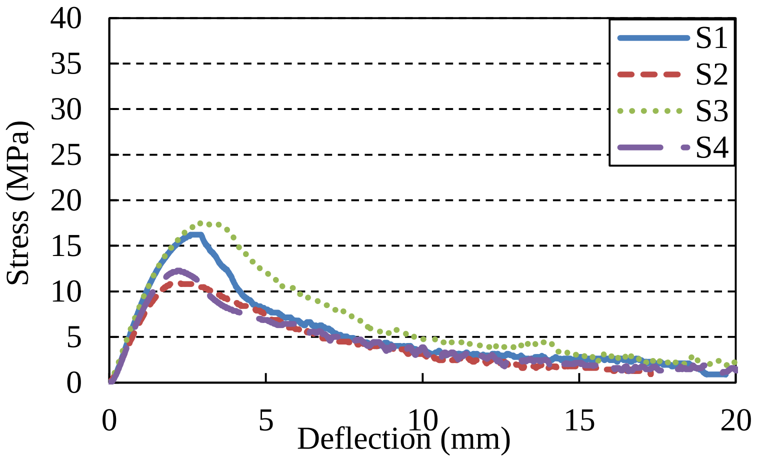
l. The stress-deflection curve of biomass board LF-2



m. The stress-deflection curve of biomass board LF-3



n. The stress-deflection curve of biomass board LF-4



o. The stress-deflection curve of biomass board LF-5

Fig.4- 3 The stress-deflection curve of biomass boards

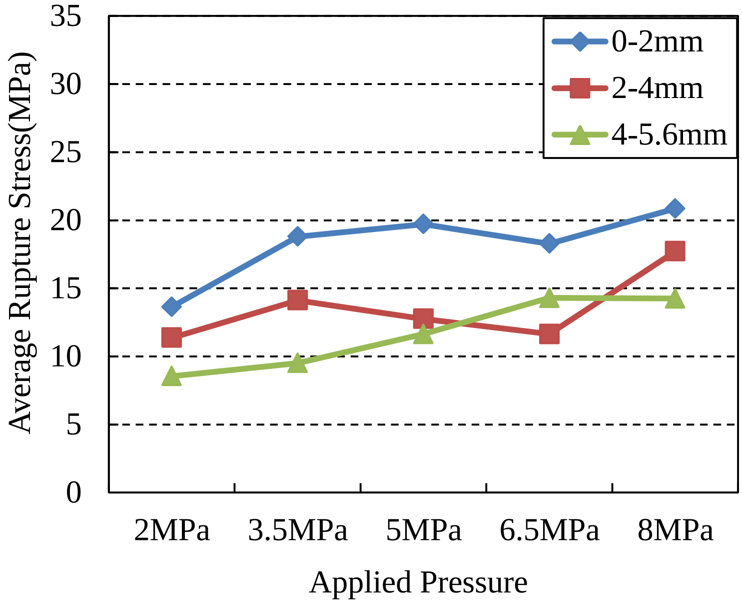


Fig.4- 4 The average rupture stress of biomass boards

4.6.3 Results of tensile test

3 specimens for tensile test were cut from every biomass board respectively. The 3 specimens were named S1, S2 and S3 from every biomass board. The relationships between stress and elongation of 15 biomass boards are shown in from Fig.4-5.

From biomass board SF-1, according to the curve of stress-elongation, for the 3 specimens, the stress increased with the increase of elongation until the stress reached maximum value. At the time, specimens fractured. And then, the stress decreased to zero gradually. The maximum value of stress was named as rupture stress. Rupture stresses of the 3 specimens were 6.32MPa, 10.32MPa and 10.41MPa which were shown in from Fig.4-5(a).

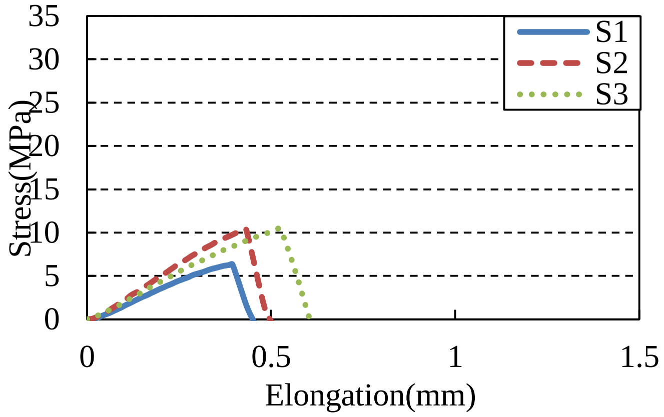
The stress-elongation curves of specimens cut from the other 14 bio-boards were similar to the biomass board SF-1, which were shown in from Fig.4-5(b) to Fig.4-5(o). The relationship of stress-deflection for every specimen from one biomass board was similar while the rupture stresses were different from each other. The rupture stresses of biomass board SF-2 were 16.35MPa, 14.77MPa and 12.54MPa.

The rupture stresses of biomass board SF-3 were 9.35MPa, 15.16MPa and 13.85MPa.

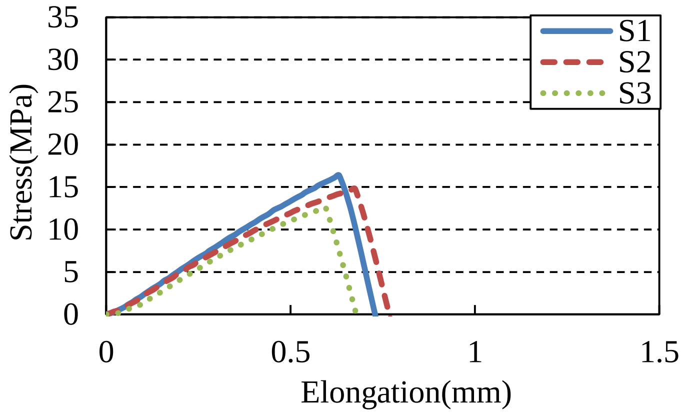
The rupture stresses of biomass board SF-4 were 33.11MPa, 23.03MPa and 13.18MPa.

The rupture stresses of biomass board SF-5 were 7.69MPa, 9.95MPa and 14.75MPa.

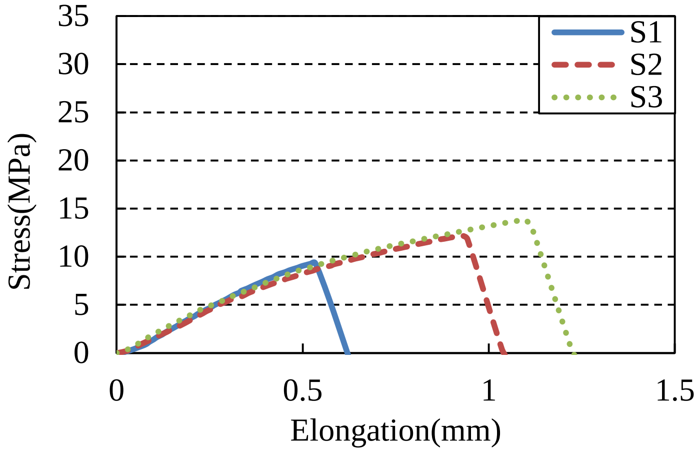
Average rupture stress comparison is showed in Fig.4-6.The maximum ruptures stress 16.02MPa appeared in biomass board SF-4 whose fiber length was between 0-2mm and max pressure was 5MPa.



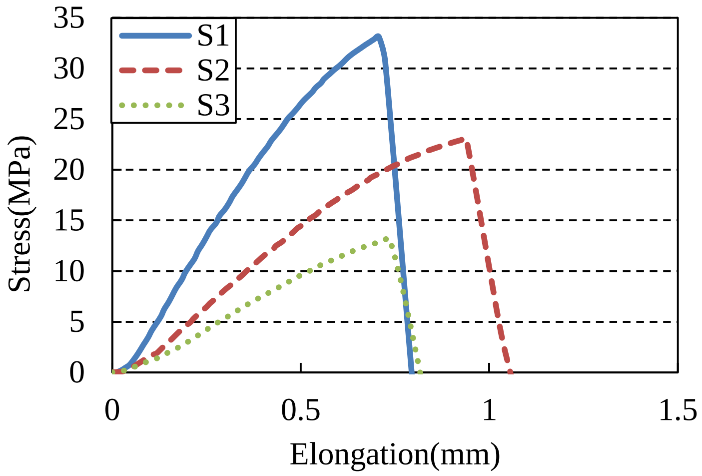
a. The stress-elongation curve of biomass board SF-1



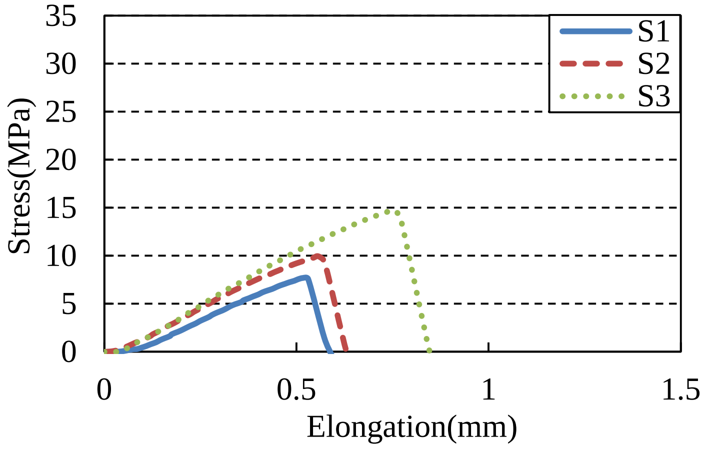
b. The stress-elongation curve of biomass board



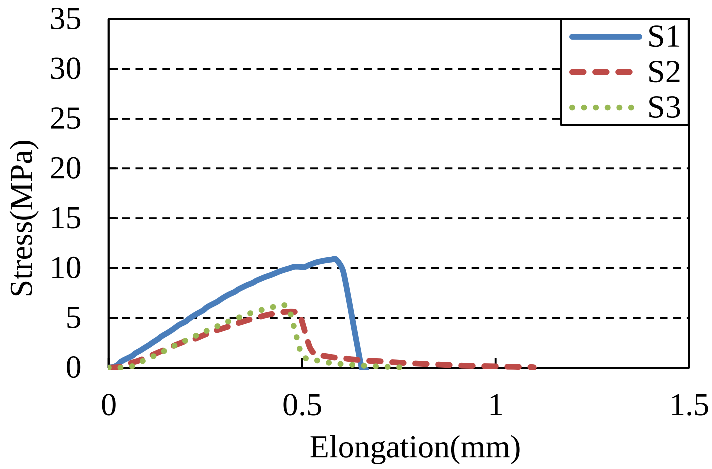
c. The stress-elongation curve of biomass board SF-3



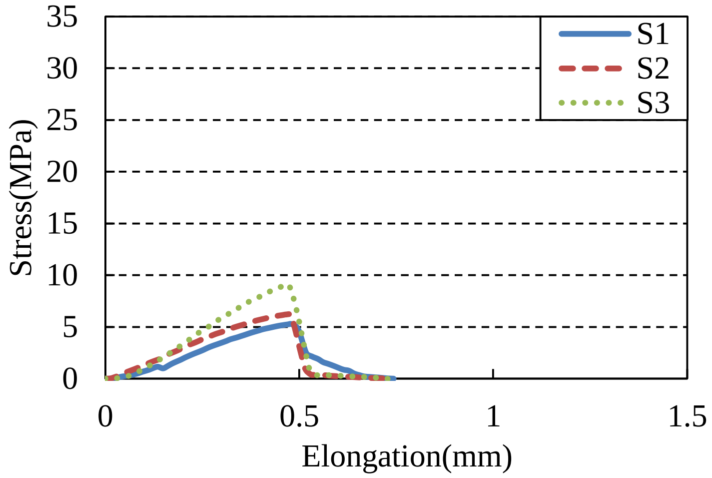
d. The stress-elongation curve of biomass board SF-4



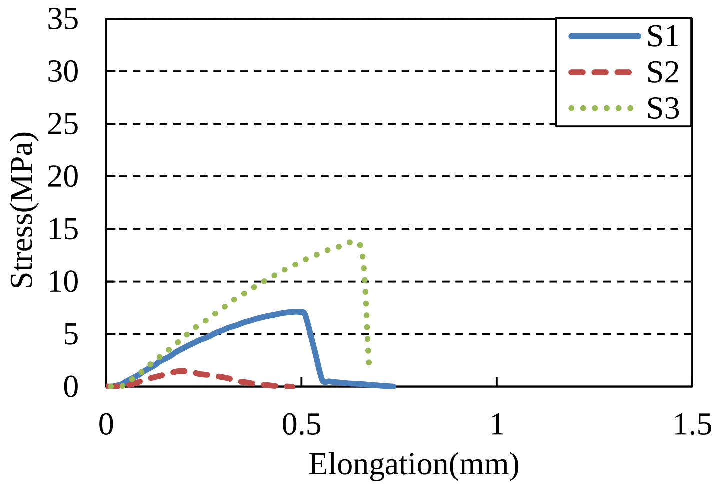
e. The stress-elongation curve of biomass board SF-5



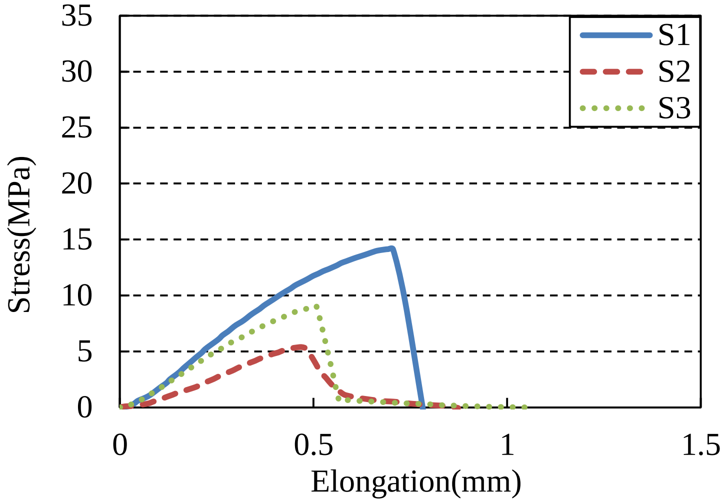
f. The stress-elongation curve of biomass board



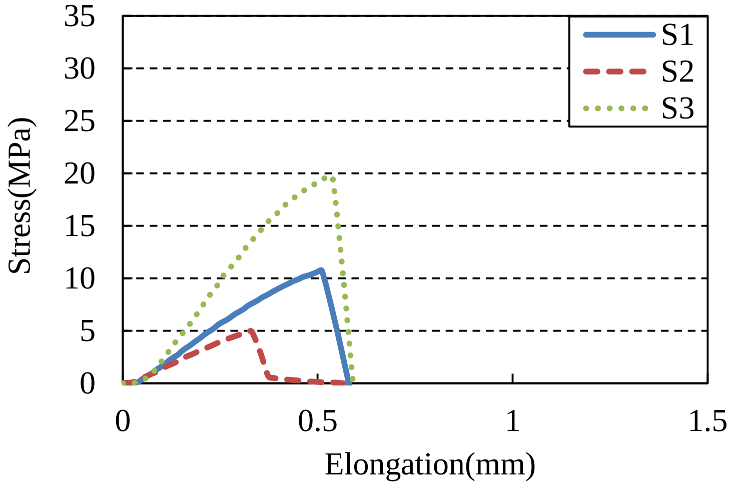
g. The stress-elongation curve of biomass board MF-2



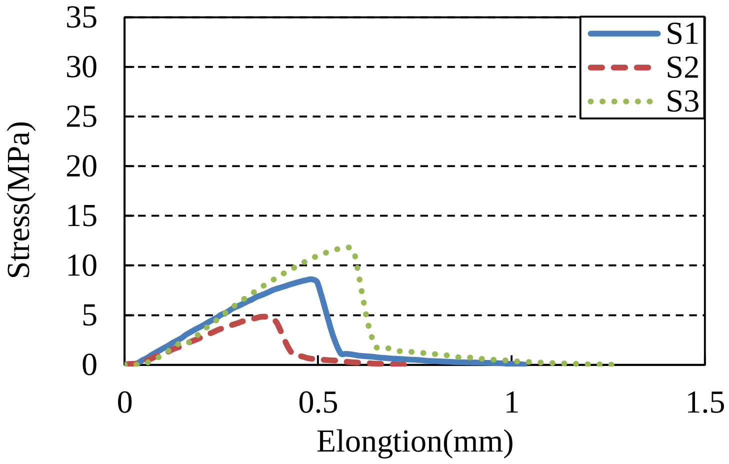
h. The stress-elongation curve of biomass board MF-3



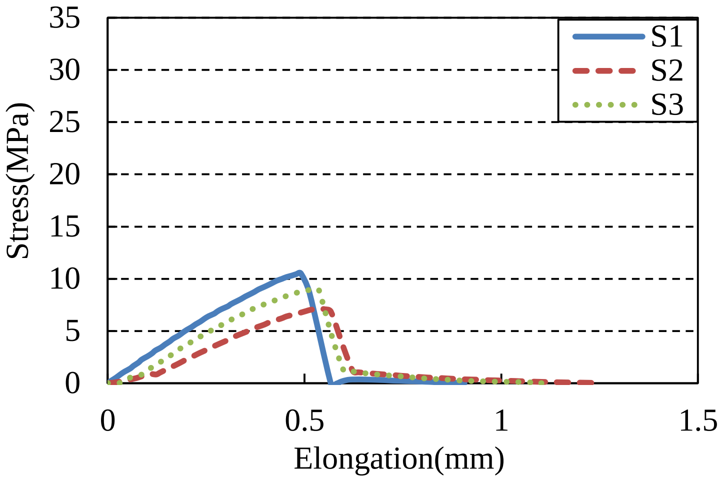
i. The stress-elongation curve of biomass board MF-4



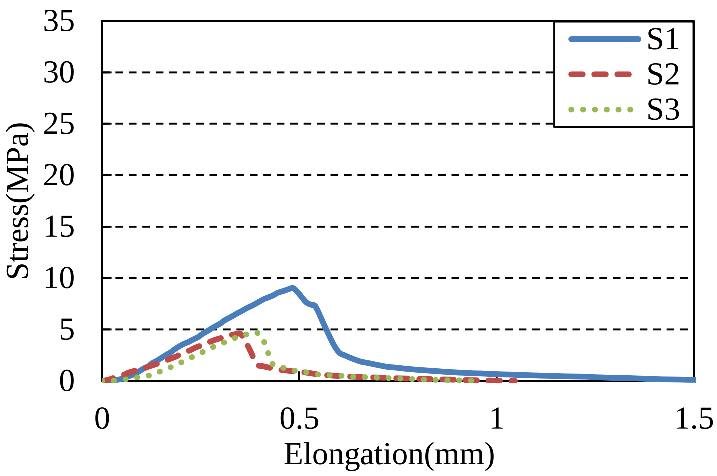
j. The stress-elongation curve of biomass board MF-5



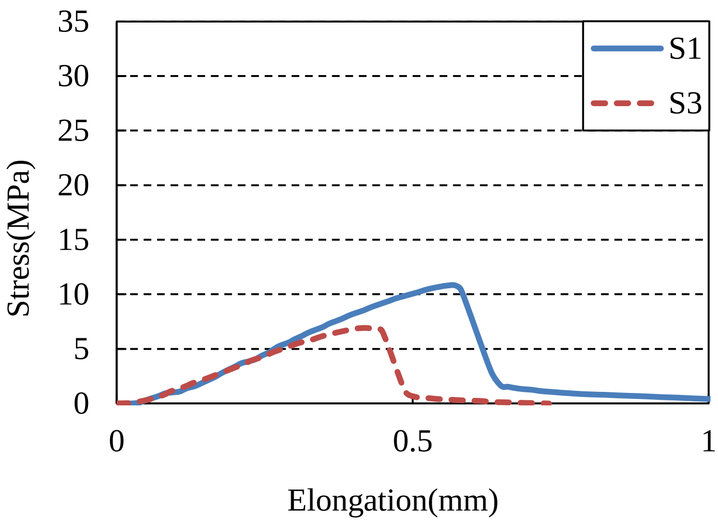
k. The stress- elongation curve of biomass board LF-1



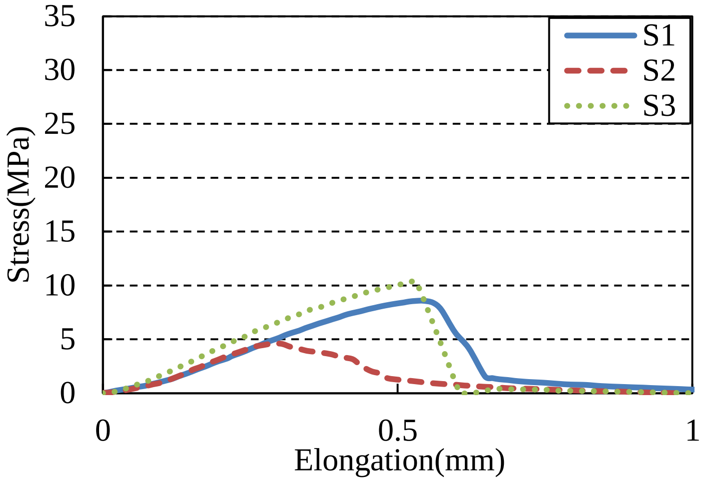
l. The stress- elongation curve of biomass board LF-2



m. The stress- elongation curve of biomass board LF-3



n. The stress- elongation curve of biomass board LF-4



o. The stress- elongation curve of biomass board LF-5

Fig.4- 5 The stress-elongation curve of biomass boards

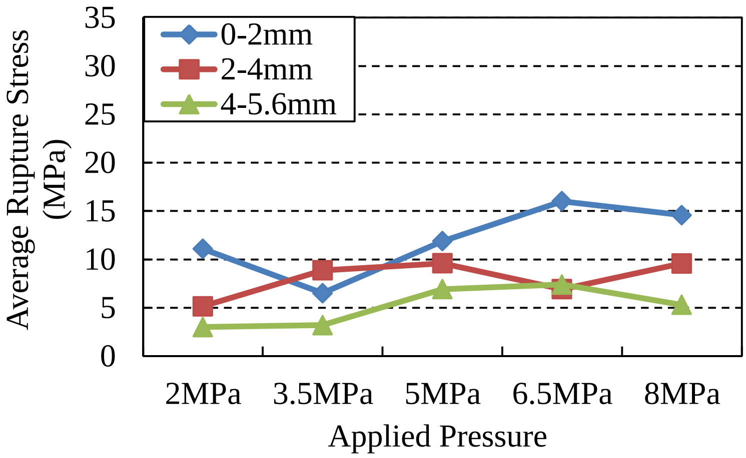


Fig.4- 6 The average rupture stress of biomass boards

4.7 Conclusions

The main objective of this study was to investigate the possibility of making biodegradable biomass board using rice straw and the relationship between refining and mechanical properties of it. 15 pieces of biomass boards were made by the processes of cutting, soaking, refining, sieving, forming and drying with the same heating temperature 110°C, three kinds of fiber length 0mm<SF≤2.0mm, 2.0mm<MF≤4.0mm, 4.0mm<LF≤5.6mm and different applied pressures 2.0MPa, 3.5MPa, 5.0MPa, 6.5MPa, 8.0MPa. Mechanical

properties of the biomass boards were investigated by three-point bending test and tensile test. It can be concluded as follows:

1) According to the result of this study, the rice straw biomass board was made successfully using the proposal method. The making process including cutting, soaking, refining, forming and drying was appropriate. In addition, no chemical adhesives or chemical compounds were added in whole making process of biomass board. The biomass board made in this study is biodegradable, and is an environment-friendly material.

2) 15 pieces of biomass board were produced in different lengths of fibers. According to the results, the maximum value of rupture stress in bending test was 19.71MPa which appeared at applied pressure of 5MPa and made by SF. The maximum value of rupture stress in tensile test was 16.02MPa which also appeared at applied pressure of 6.5MPa and made by SF. The biomass board made from the SF has a better mechanical performance than others. Therefore, refining degree has an effect on the mechanical properties of biomass board.

3) Consequently, according to the mechanical properties of biomass board, it can be considered for applications in agriculture, packaging and building construction.

CHAPTER 5. Conclusion

The research is focus on development of biodegradable biomass board using rice straw. According to the result of this study, the rice straw biomass board was made successfully without any chemical adhesives or chemical compounds using the proposal method. Above all, the biomass board can replace wood products and plastic products in some place, The results showed that it is not only can reduce the utilization of wood, oil and other fossil energy, and reduce plastic pollution to the environment, of course, the crop straws resources are more efficiently utilized.

This study mainly was concluded conclusions as follows:

1) Referred to the related information, understood of the definition of biomass, biomass materials and its present development situation.
2) Applied pressure has an effect on the mechanical properties of biomass board. According to the relationship between bending stress and deflection or the relationship between tensile stress and elongation, when the heating temperature was 110℃， the maximum value of average rupture stress for 5 biomass board appeared at the maximum applied pressure 5MPa.
3) Heating temperature has an effect on the mechanical properties of biomass board. According to the relationship between bending stress and deflection or the relationship between tensile stress and elongation, when the maximum applied pressure was 5MPa，the maximum value of average rupture stress for 5 biomass board appeared at the heating temperature 190℃.
4) Refining degree has an effect on the mechanical properties of

biomass board. According to the relationship between bending stress and deflection or the relationship between tensile stress and elongation, when the biomass boards were made of the fiber length between 0mm to 2mm，the average rupture stress has a better mechanical performance than others.

5) Compared with the ordinary wrapping paper board used for packaging and polystyrene board used for food pallets were measured, the biomass board is 1.56~3.25 times stronger than the ordinary wrapping paper board, and 1.93~4.02 times stronger than polystyrene board. In addition, Consequently, biomass board can be considered for applications in agriculture, packaging and building construction.

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