Utilization of woody resources by compressive molding process with high-pressure steam - development of biomass boards fabricated from wood residue without chemical adhesives -

Ken-ichi KYOMORI
Dept. Bioprocessing, Graduate School of Engineering, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan, TEL: x81-58-293-2922 FAX:x81-293-2922 e-mail: kyom@cc.gifu-u.ac.jp
Masashi SUZUKI and Siaw ONWONA-AGYEMAN, Mikiji SHIGEMATSU and Mitsuhiko TANAHASHI
Dept. Bioprocessing, Faculty of Agriculture, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan, TEL:x81-58-293-2917 FAX:x81-293-2917 e-mail: tanah@cc.gifu-u.ac.jp
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"The steam extraction of essential oil and compressive molding of woody resources by high-pressure steam" had been developed in our laboratory. Using this technique, we obtained essential oil and biomass boards from wood residue. In this paper, the mechanical properties of the boards fabricated under various steam conditions were investigated.

Keywords: High-pressure steam, Biomass boards, Mechanical properties, Steam extraction method

I. INTRODUCTION
Previously, we developed "The compressive molding process of wood by the high-pressure steam technique".1-2 By using this technique, a log wood was compressively molded by a pressing component with molding blocks and the deformed shape was fixed by high-pressure steam without chemicals. In this way, the mechanical properties of softer material can be improved. Next, we applied it to the fabrication of boards from woody resources. The boards are fabricated by the high-pressure steam technique without adhesives and are referred to as the "biomass boards". Raw materials of biomass board include forest residues (thinnings, branches and leaves, etc) and industrial lumbering residues (sawdust, sawmill and chips, brocks, etc), agricultural residues (rice straw, husk, corn stack...). These boards can be used as building materials (inner wall, soundproof materials...) and furniture, agricultural use (fertilizer, moisture-retention material...), weed suppressers and erosion control structures and so on. In our previous works,3-5 mechanical properties of the biomass boards from various sawdust species (hard & softwood) were determined.

Moreover, we had interest in the liquid that is squeezed out from the material during the compressing stage. Generally, essential oil in wood is used as perfume, antibacterial drug, for medical purpose etc. Thus, we developed the steam extraction method by the high-pressure steam for extracting the essential oil. While essential oil was extracted, the biomass board was fabricated by the developed new apparatus. The purpose of our present study is to verify the validity of this method and to analyze extraction mechanism, constructing the fundamental data needed for industrialization. In this paper, we investigated the relationship between steam pressure and the yield of extracted essential oil as well as the mechanical properties of fabricated boards. By means of this developed eco-process, we can obtain the essential oil and biomass boards from wood residues.

II. MATERIAL AND METHODS
II-A. Steam extraction method by high pressure steam

Figure 1 shows the schematic diagram of the developed apparatus for "The steam extraction of..."
essential oil and compressive molding of woody resources by high-pressure steam. High-pressure steam is injected in the airtight-autoclave and inside the material. Essential oil in the material evaporates and is stored within the steam drain in the "Distillation pot". Stored essential oil is distilled in the pot, the distilled gas condenses into liquid in the "Cooler" and it is stored in the "Store pot". In the store pot, lower density constituents float on water, while higher density constituents stay at the bottom. In the next step, the residue (softened material) is compressed by a pressing component and the steam extraction process continues.

Fig. 1. Schematic diagram of "Steam extraction method by high-pressure steam".

II-B. Material and board fabrication (extraction)

The material used for the experiment was 400g of air-dried of Western Red cedar (Thuja plicata) sawdust. High-pressure steam (0.4-1.6 MPa / 0.2MPa) was injected in the airtight-autoclave for 60min in total. The processes in this technique are briefly introduced in the following stages:

1) Steaming and softening stage

The high-pressure steam inside softens the material for 40min. The chemical constituents are extracted through the passage of steam.

2) Compressing stage

Softened material (the residues) is compressed to a target density of about 1.0g/cm³ by the pressing component (Capacity of max-pressure, 15MPa).

3) Fixing stage

Deformed shape of compressed material is fixed by high-pressure steam for 20min. The fixation is caused by the structural change of cellulose crystals and partial chemical degradation. The steam extraction process continues.

Fig. 2. Flow chart of board fabrication and extraction of essential oil.

II-C. Sample preparation and testing

The fabricated biomass boards were of dimensions ø 200mm and 10mm thick and it was cut for the determination of mechanical properties. Prepared samples were investigated including modulus of elasticity, modulus of rupture, surface hardness, internal bond strength thickness swelling and dimensional stability in accordance with JIS A 5908-1994. In the dimensional stability test, samples were subjected to cyclic conditions of oven-drying for 24h and wetting in water for 24h. After the fifth oven drying treatment D5, these were boiled and finally oven-dried. Steam pressure = SP.

III. RESULTS AND DISCUSSION

III-A. Essential oil yield and mean density of biomass board

Steam drain (water) in the liquid obtained by the steam extraction method was taken away for chemical analysis and the separated oil was named "essential oil" in this paper. Figure 3 shows the yield of extracted essential oil and the rate of weight decrease. Both quantities increased with a rise in steam pressure. This result indicates that more oil distilled by steam at a higher temperature. The weight decrease was caused by the elution of sugar originating from hemi-cellulose.

Fig. 3. The yield of essential oil and percentage weight decrease of material.
The determined mean densities of fabricated biomass boards are shown in Fig.4. The value for SP=0.4 was the lowest, because the raw material was not sufficiently softened and compressed. Over SP=1.2, it seems that the increase of cellulose crystallinity and chemical degradation had occurred.

**III-B. Modulus of rupture (MOR) and modulus of elasticity (MOE)**

It has been reported that MOR and MOE values for particle boards depend on density in previous report by many authors. The measured values of MOR and MOE showed similar trends as in Fig.5 and Fig.6. 1.2MPa boards had the highest value. For reference, the value of MOR is nearly acceptable according to JIS standards (JIS A5905) for "Hard board" HB type S20 and is also acceptable for "Particle board" RN type 18 (JIS A5908). The minimum standard value of MOE for RN type 18 was over 3.0GPa. The fabricated 1.2MPa boards fulfilled this standard. For results of over SP=1.2, the value of MOR and MOE reduced with a rise in steam pressure. These were caused by deterioration of material components under higher temperature.

**III-C. Intentional bond strength (IB) and surface hardness (SH)**

In order to determine the physical adhesiveness, the internal bond strength of samples was measured. By excluding the SP=0.4 sample (density was the lowest), IB gradually decreased with a rise in steam pressure (Fig.7). Incidentally the value of IB for boards fabricated by non-extraction process was 0.80MPa. It seems that the value of IB depends on the yield of essential oil.
III-D. Thickness swelling (TS), dimensional stability (Thickness changes and weight changes)

There was a clean tendency in thickness swelling values as shown in Fig.9. The TS values below $SP=0.8$ were higher as the deformed shape of the boards was not sufficiently fixed.

It must be noted that the fluctuation in thickness changes and weight changes was the least for the condition of $SP=1.6$ (Fig.10). Samples with SP values exceeding $SP=1.2$ contained little dissolved sugar as adhesives, so the thickness gradually increased and the amount of water absorption was not much.

IV. CONCLUSION

We successfully developed the apparatus for the utilization of woody resources “Extraction of essential oil and compressive molding with high-pressure steam”. The yield of essential oil extracted by this method was better than that by other methods. According to the mechanical properties of the fabricated biomass boards under various conditions, the 1.2MPa boards had the most satisfactory strength values and the 0.8MPa boards were the most stable with regard to water. By using developed eco-process, useful essential oil and adhesive-free biomass boards were simultaneously obtained by wood residue without using chemicals.

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REFERENCES


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