Mechanical modification of softwood pulp fibers using a novel lightweight vertical bar plate

HO-GYUNG GU, BYUNG-GUL MIN, JI-YOUNG LEE, SEE-HAN PARK, MIN-SEOK LEE, CHANG-YOUNG LEE, AND CHUL-HWAN KIM

ABSTRACT: Refiner plates made using sand casting have a draft angle, which results in a trapezoidal bar shape. These trapezoidal bar plates have a limited throughput compared to the vertical bar plates, and eventually the edges of the bars become dull, resulting in longer time to reach the target freeness and shorter service life. The new lightweight refiner plate with a bar insertion method into a plate base was developed by selecting an aluminium-based alloy as the plate base material and a stainless steel alloy with high wear resistance as the bar material. The lightweight plate with sharp bar edges was very effective in reducing refining energy by reaching the target freeness faster than the sand-cast bar plate. Finally, the lightweight sharp bar plate, which weighed only about half the weight of the cast bar plate, was expected to significantly contribute to easy replacement, improved paper quality, and larger throughput without excessive loss of fiber length.

Application: By combining aluminum alloy and stainless steel alloy, a lightweight vertical bar plate suitable for softwood pulp was introduced. The lightweight vertical bar plate has a sharper bar edge, unlike the general cast plate, and it allows a large amount of material to pass, which is much more advantageous in terms of energy saving and production. In particular, even if the bar surface wears out during the continuous refining process, the sharpness of the bar edge is maintained and the life of the plate can be extended.

The refining process is the most important part of papermaking, but it is the biggest energy consumer in stock preparation. Thus, saving energy during refining leads to a reduction in a paper machine's operating cost and therefore also significantly contributes to improving the market competitiveness of the paper industry [1]. As a result, the paper industry has been exploring various ways to save energy during the refining process.

In general, refiner plates have been manufactured using conventional casting technology, which requires a 3°–5° minimum draft angle. This small angle helps the pattern to be removed without damaging the sand mold. If there is no draft angle in the sand casting, part of the molding sand will stick to it when the pattern is removed, which can damage the sand mold [2,3]. The draft angle of the bars sacrifices hydraulic capacity and bar edge sharpness [4]. In addition, the refiner plate segment manufactured using sand casting is very heavy, and its replacement requires considerable time and labor.

Voith reduced the weight by leaving the rear side of the refiner plate base empty without filling. In order to overcome these limitations of the cast plate, some refiner plate manufacturers have been working on eliminating the draft angle and reducing the weight of plate segments. Valmet has developed a bar plate with a draft angle of approximately 0.75°–1.5° using its trademarked PowerCast technology [5]. This technology contributes to extending the service life of the plates, but it does not significantly reduce their weight. Andritz has developed a product that assembles a bar plate onto a lightweight plate base using Durabond technology to reduce the weight of the refiner plate segment without the draft angle [6]. Andritz uses precision lasers to cut bars from stainless steel, which are then inserted into the laser-cut slots with proprietary bonding agents in the base plate. AFT, part of the global Aikawa Group, commercialized a fine bar manufacturing technology with no-draft angle by adopting a diffusion bonding technology that joins two different metals. This process has limitations in alloy selection and failure in plate weight loss because a two-step welding process must be applied. AFT has also developed mini segments that can be mounted on the adapter plate that is bolted to the refiner's mounting surface [4,7]. This technology makes plate replacement easier by simply minimizing segment size and making it lightweight. Instead, however, the number of segments to be replaced is increased. The Indian company Parason manufactured a plate without the draft angle by combining welding, computer numerical control (CNC) machines and laser machines, but this technique did not reduce plate weight. Lee et al. [8] introduced a platemaking technique without the draft angle using a precision casting method, but it was difficult to mass produce due to the heavy weight and the high defect rate during the casting process. In addition, some techniques, such as tungsten inert gas (TIG) welding

	Arithmetic Mean Fiber Length, mm	Length-weighted Mean Fiber Length, mm	Fiber Width, µm	Coarseness, mg/100 m
SWBKP	1.08	2.24	26	5.2

I. Fiber dimensions of long-fibered softwood bleached kraft pulp (SWBKP) used for refining.

or diffusion bonding for bars with a zero draft angle, have been introduced for making fine bar plates but have not attracted attention due to problems such as reduction of stock throughput or fiber jams between bars.

The new plate manufacturing technologies mentioned previously have paved the way for the manufacture of vertical fine bars or ultra-fine bars capable of low intensity refining. However, the refiner plates manufactured using the previously noted technologies are burdening paper companies due to their high price. To overcome these limitations, this study attempted to reduce the manufacturing cost by simplifying the plate manufacturing method, which will contribute to cost reduction, refining energy savings, and quality improvement for paper mills. We first introduce a manufacturing technology for lightweight bar plates suitable for long-fibered biomass sources and compare the performance between a conventional cast bar plate with the draft angle and a lightweight vertical bar plate.

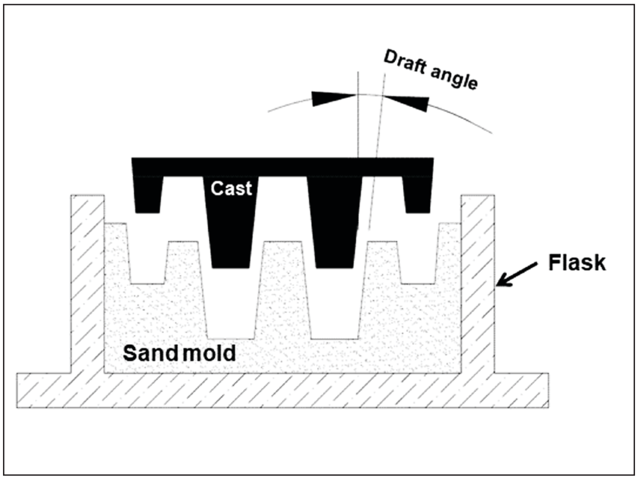
MATERIALS AND METHODS

Raw materials

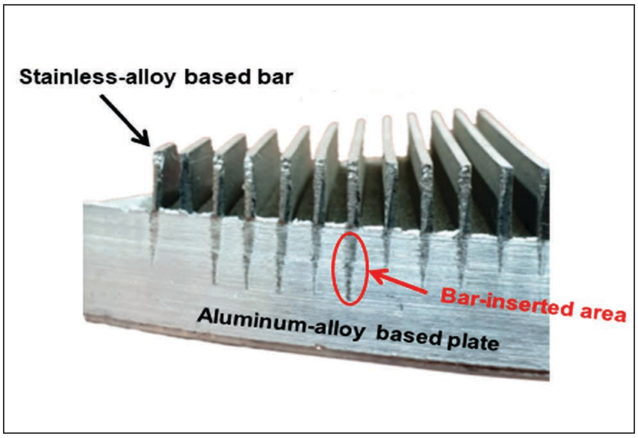
Long-fibered kraft pulp was supplied from the Moorim Paper MFG Co. Ltd. mill in Jinju, Korea. It was torn into small pieces and soaked in distilled water for over 4 h before disintegration using a Valley beater. The dimensions of the woody pulp are summarized in **Table I**.

Manufacturing process for the lightweight refiner plate

Most refiner plates have been manufactured using a metal casting process, with sand as the mold material. It is not good for the sand casting to have surfaces that are normally perpendicular to the direction along which the cast will be ejected from the sand mold. This may cause the cast to stick in the sand mold, and forceful ejection will cause damage to both cast and mold. Therefore, most casting refiner plates have inclined surfaces with a small draft angle (3°–5°), as shown in **Fig. 1**. Unfortunately, this draft angle in the grooves between adjacent bars leads to the reduction of both bar sharpness and throughput.



1. Draft angle given to refiner bars for sand casting.

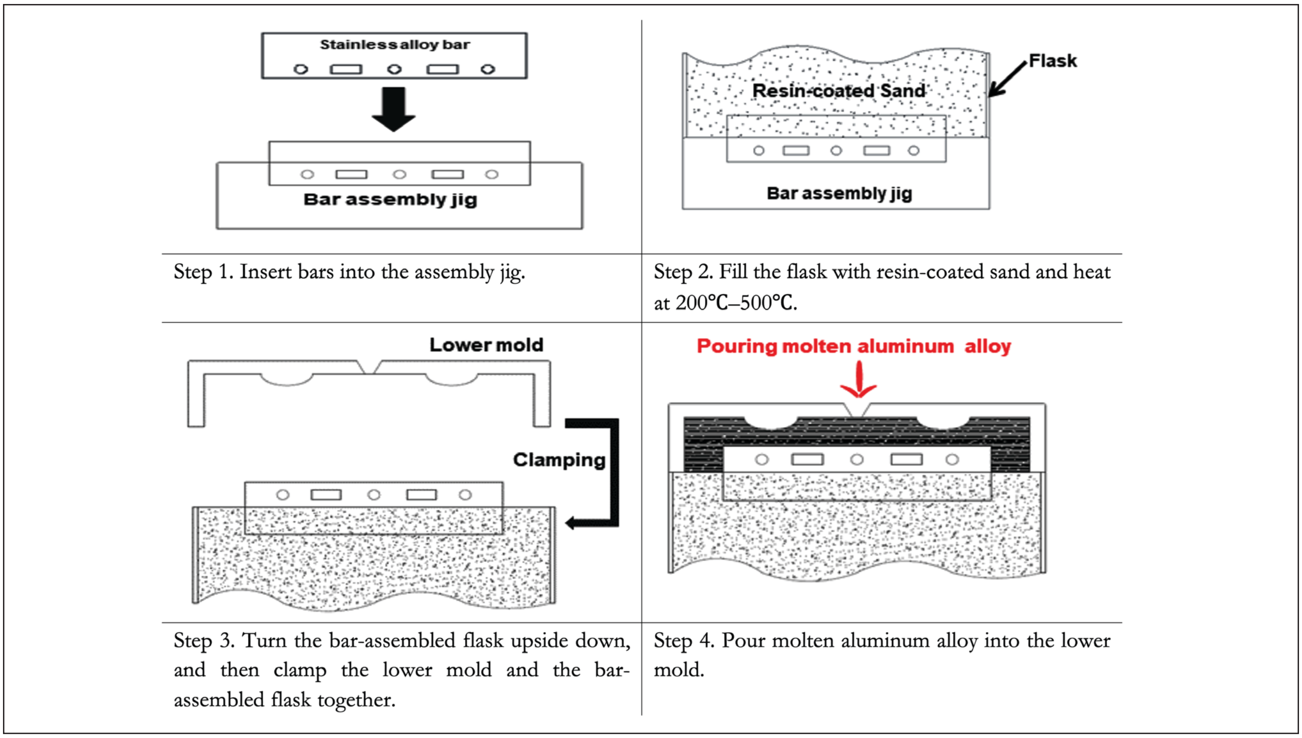


2. Lateral view of a new refiner plate segment.

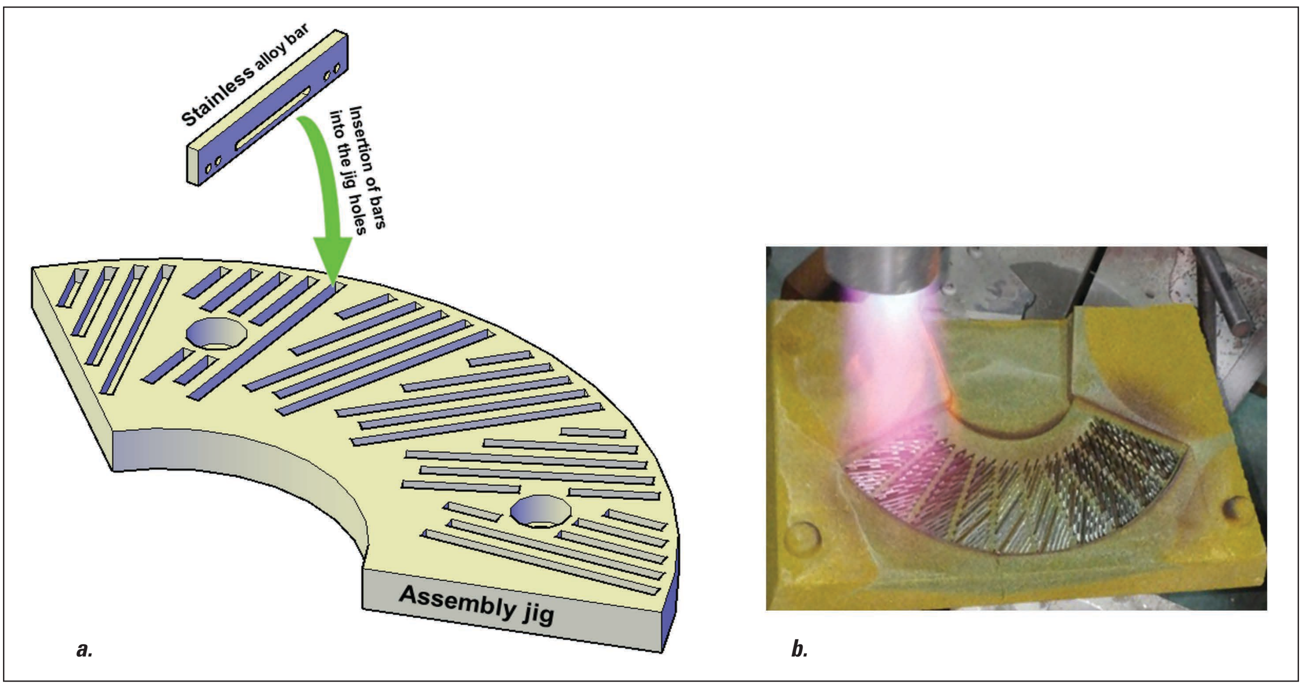
A new manufacturing technology was developed to remove the draft angle formed on the bar of the finer plate. The new bar plate manufacturing technology, which is a double-junction method of heterogeneous metals, can eliminate the draft angle of the bar and dramatically reduce the weight of the bar segment. Moreover, the sharpness of the bars can be improved more than that achieved with the sand casting, and the throughput of pulp stock can be multiplied.

As shown in **Fig. 2**, the new finer plate is composed of bars of a stainless-alloy material, 420J2, which is resistant to both abrasion and corrosion, that are inserted into the base plate of the aluminum-alloy material, 1B, of the lightweight plate. Each bar component part is heat-treated for hardening before it is assembled to the bar assembly jig hole.

The first step to make a lightweight plate is to insert the heat-treated bars into an assembly jig (Step 1 in **Fig. 3** and **Fig. 4a**). The flask is put on the bar-inserted assembly jig



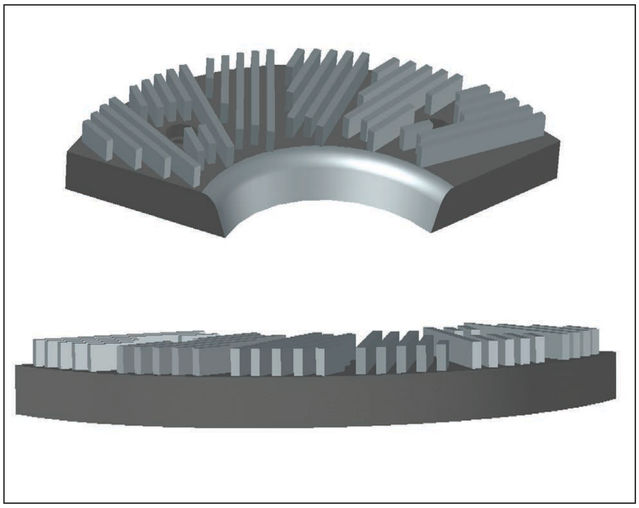
3. Manufacturing process for a light bar plate.



4. (a) Process to insert a stainless alloy bar into a hole in the assembly jig (pattern), and (b) heat treatment process against the bar-assembled sand mold.

and packed with a resin-coated sand. The sand is heated up to 200°–500° for curing (Step 2 in Fig. 3). When the cured flask is lifted from the assembly jig, the stainless alloy bars are transferred to the upper mold on which the lower mold is coupled (Step 3 in Fig. 3). As shown in Fig. 4b, the bar-assembled jig is further heated for complete curing.

Molten aluminum alloy metal is carefully poured in to fill the cavity between the clamped molds (Step 4 in Fig. 3). At that time, while the molten metal fills up the holes of the discrete bars, the bars are rigidly fixed to the plate base. Once the metal is completely cooled, the hardened sand is removed to get the casting. For reference, a bar that is 4-cm



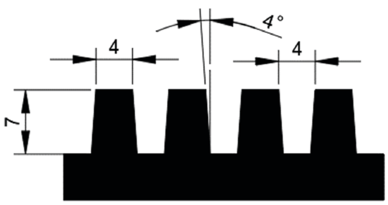
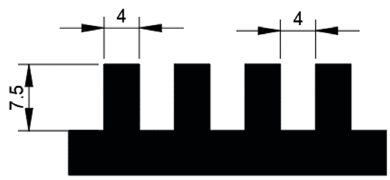
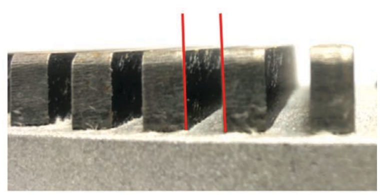
5. Three-dimensional model for the lightweight vertical bar plate for softwood kraft pulp.

wide and 14-cm long weighs about 24 g. A three-dimensional (3D) model of the lightweight plate without a draft angle is shown in **Fig. 5**.

Table II shows the dimensions of the casting segment and the lightweight segment used in the experiment. The draft angle of the casting segment is 4°, while the light segment has vertical bars inserted without a draft angle. When comparing the number of bars from the two segments, the number of bars at the greatest length (17.5 cm) was 108 in the casting segment, but only 60 in the lightweight segment. The number of bars with shorter lengths was also smaller in the lightweight segment, except for the 2.5 cm bar.

Refining

The soaked pulp specimens made from bleached softwood kraft pulp were disintegrated using a Valley beater without

	Casting Segment with Draft Angle		Lightweight Segment without Draft Angle	
Bar dimension, mm				
Bar angle	15°		15°	
Bar plate				
Bar shape				
Draft angle	4°		0°	
Bar no. by length	**2.1 cm**	90	**2.1 cm**	54
	2.5 cm	72	**2.5 cm**	90
	16.7 cm	54	**11.5 cm**	15
	17.5 cm	108	**17.5 cm**	60

II. Dimensional comparison of the casting segment and the lightweight segment for softwood kraft pulp.

a load at a consistency of 1.57±0.04% for at least 3–5 min. When the pulp was properly disintegrated, extra water in the pulp stock was removed to adjust its consistency to around 4%–5% for refining.

The refining was conducted at 1500 rpm with a laboratory single disk refiner (KOS1 Co.; Gimhae, Korea) with two different plates (12-in. diameter). The pulp stock was consecutively refined to achieve a CSF of around 190 mL. To calculate the net refining energy during refining, the no-load power required when the refiner is in the idling was subtracted from the refining energy for each refining step until reaching the target freeness. The net energy of each refining step was expressed as the total specific refining energy (kWh/ton) by summing the net refining energy of the previous step.

Measurement of pulp and paper properties

Mean fiber length and fines contents (≤0.2 mm) of softwood kraft pulp were determined using FQA-360 (Optest Equipment Inc.; Hawkesbury, ON, Canada). Handsheets for measuring the physical properties of the paper were made, conditioned, and tested according to TAPPI Standard Test Method T 205 “Forming handsheets for physical testing of pulp.” Their physical properties, including tensile and tear strength, were measured based on TAPPI T 220 “Physical testing of pulp handsheets.” Paper bulk was calculated using the basis weight of each sheet, and thickness was measured using the L&W caliper test (Micrometer; Kista, Sweden). Water retention value (WRV, g/g) was measured based on ISO 23714:2014 “Pulps—Determination of water retention value (WRV).”

RESULTS AND DISCUSSION

Cutting edge length and specific edge load

Table III compares the dimensions between the typical casting plate and the new lightweight plate without a draft angle. Except for the groove depth and the draft angle, the design of the casting plate and the lightweight plate did not make any significant difference. Since the lightweight segment employs a method of inserting the bars into the base plate, if the bars having the same dimensions as those of the cast plate are inserted, the molten aluminum alloy is not properly filled between the bars. In the lightweight segment, in order to ensure that the molten aluminum alloy is properly filled and firmly holds the vertical bars, the number of bars has to be reduced compared to that of the casting segment. This reduction makes a big difference in the cutting length factor (CLF) or cutting edge length (CEL) of the two plates. To compare the refining intensity of two different refiner plates, CLF and CEL were calculated according to ISO/TR 11371 “Pulps—Basic guidelines for laboratory refining” using Eq. 1 and Eq. 2:

$$SEL = \frac{P_t - P_0}{Z_r \times Z_{st} \times l \times n} = \frac{P_t - P_0}{CLF \times n} = \frac{P_t - P_0}{CEL} \qquad (1)$$

	Casting Plate with Draft Angle	Lightweight Plate without Draft Angle
Bar plate		
Bar number	108	96
CLF, m/rev	590.8	329.3
CEL, km/s	14.8	8.2
No-load power, kW	1.04	1.05
Total power, kW	5.34	3.63
Net refining power, kW	4.30	2.58

III. Cutting length factor (CLF) and cutting edge length (CEL) of refiner plates with and without a draft angle for softwood kraft pulp.

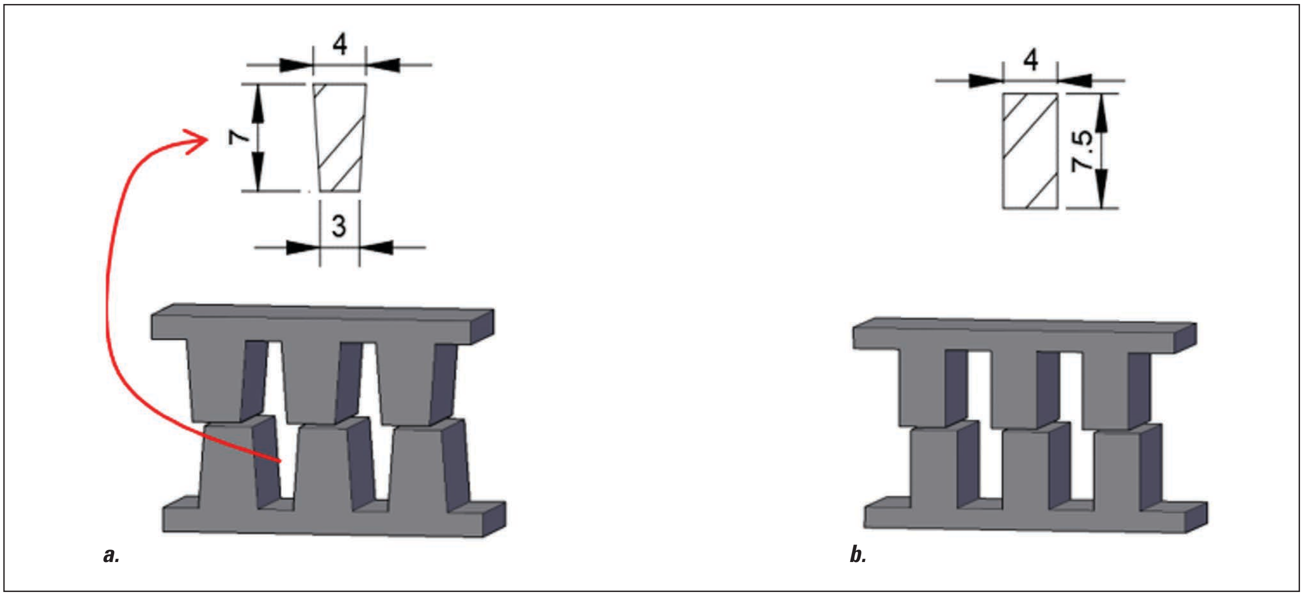
6. Weight comparison between the normal casting plate and the lightweight plate.

where:

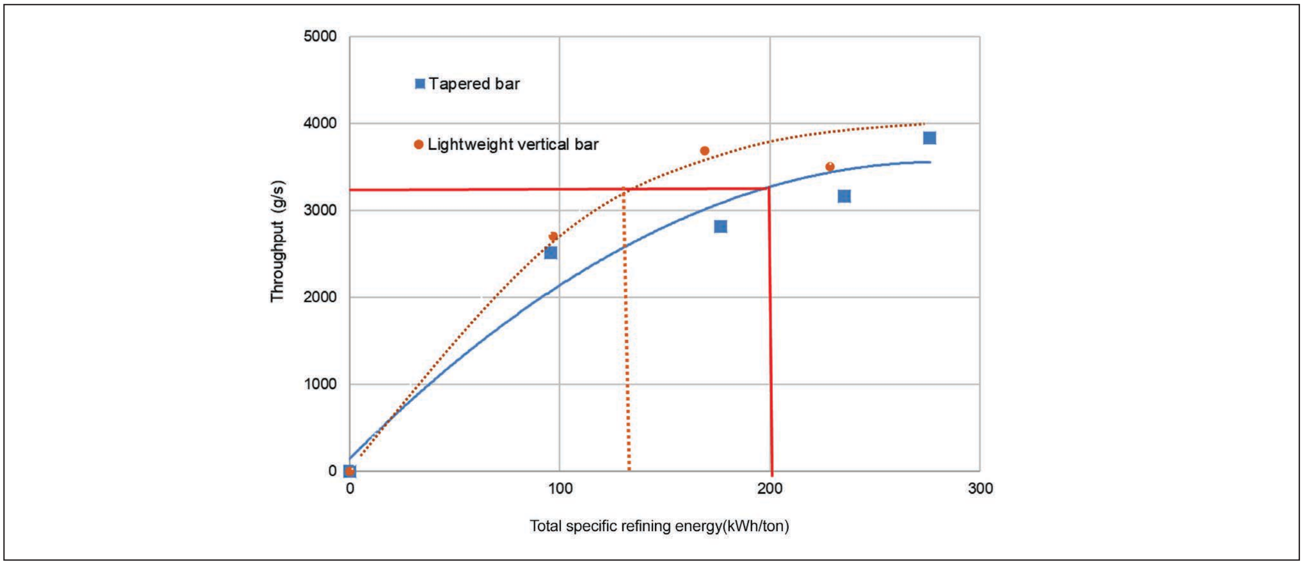
SEL	=	specific edge length, J/m, W•s/m
P_t	=	total load power, kW
P_0	=	no-load power, kW
n	=	rotation speed, rev/s
Z_r, Z_{st}	=	number of rotor and stator bars
l		bar length, km
CLF	=	cutting length factor, km/rev
CEL	=	cutting edge length, km/s

The casting plate and the lightweight plate with similar bar dimensions showed a large difference in CLF or CEL, depending on the difference in manufacturing method. As mentioned previously, a much smaller number of bars were inserted than the number of bars in the casting plate. The difference in the number of bars has a great influence on CLF or CEL. Although the normal casting plate had a CEL about twice as large as the lightweight bar plate, there was a remarkable difference in a net refining power between the casting plate and the lightweight plate. This is because the casting plate with taperzoidal bars takes longer to achieve a target freeness than the lightweight plate with vertical bars, which in turn consumes more refining energy. On the other hand, a lightweight vertical bar plate with sharp bar edges requires less energy to reach the target freeness. When fibers get caught between sharp bar edges, there is a strong tendency for them to be easily cut. Eventually, the casting plate had a larger CEL than the lightweight plate, but it consumed more refining energy, resulting in SEL similar to that of the lightweight plate that consumed less energy.

As shown in **Fig. 6a** and Fig. 6b, the lightweight bar segment with a diameter of 12 in. was about 1 kg in weight, and the normal casting bar segment was about 1.9 kg. The manufacturing technology of the lightweight plates makes the advantage more pronounced as the plate diameter increases. For example, one segment of a German-made 38-in. disk plate used by a Korean paper mill weighs about 9.7 kg, but a lightweight segment weighs only 5.0 kg (Fig. 6c and Fig. 6d). The weight of the refiner plate is greatly



7. Comparison of feeding areas of the pulp stock into the grooves: (a) trapezoidal groove, and (b) rectangular groove.



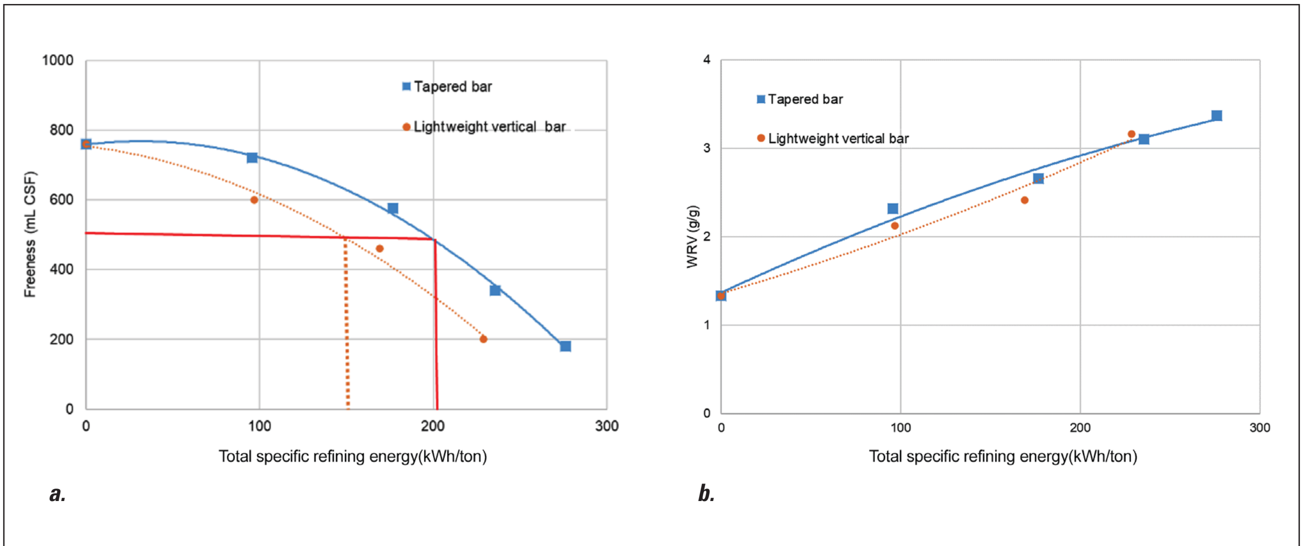
8. Throughput comparison of the pulp stocks from the trapezoidal groove and the rectangular groove.

influenced by the weight of the plate base. In particular, because the base plate is made of aluminum alloy, the lightweight plate is about twice as light as the cast plate. This was also confirmed with a 38-in. lightweight fine bar plate made in the same way. The weight reduction of the plate segments actually makes the plate replacement easier, faster, and safer.

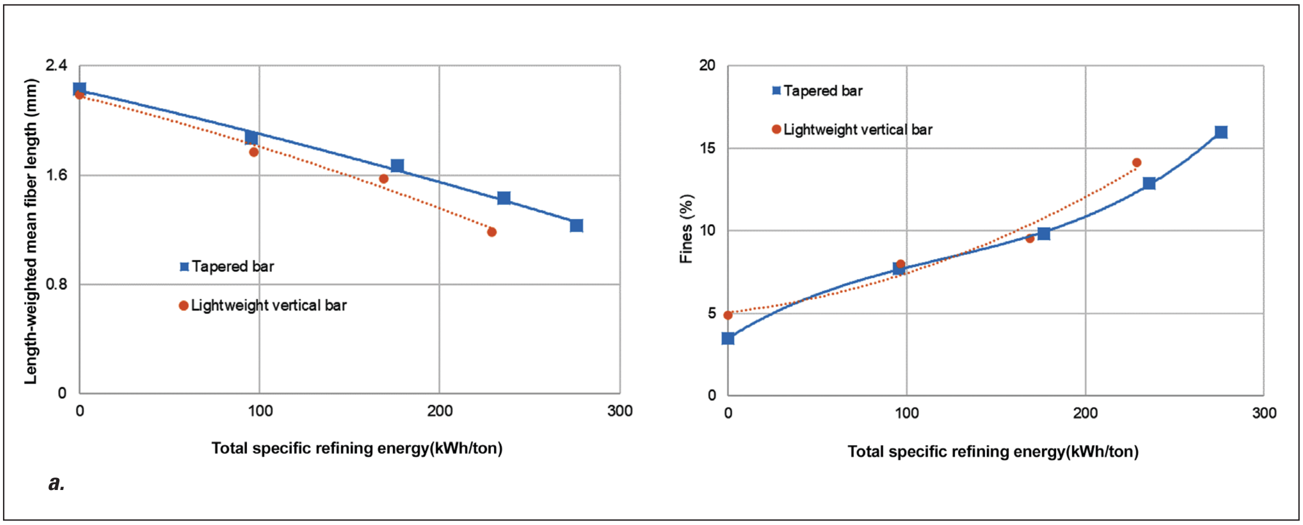
Throughput comparison between two different plates

When the same amount of pulp stock was fed into the refiner plates with the two different bar shapes, the areas of the groove inlets were compared, as shown in **Fig. 7**. When applying a new filling of the refiner plate, you should always consider the throughput. No matter how excellent the refining effect is, if the throughput is reduced, it will be a negative factor for the overall production. The cast bar with a trapezoidal groove had an inlet area of 24.5 mm^2, and the rectangular lightweight bar had an area of 30 mm^2. Even if the heights and widths of both bars are the same, the vertical bar plate with the rectangular groove has a larger entrance inlet area than the wedge-shaped bar plate with the rectangular groove.

As refining progressed, the amount of pulp stock passing through the rectangular groove was 8%–11%, which is greater than that passing through the trapezoidal groove at a given time (**Fig. 8**). This means that the vertical bar plate can contribute to the increase of the productivity of a paper mill by processing more pulp stock during refining at a given time. In addition, even if the bar surface is



9. Freeness (a) and water retention value (b) of pulp fibers refined by bar plates with and without a draft angle, respectively.



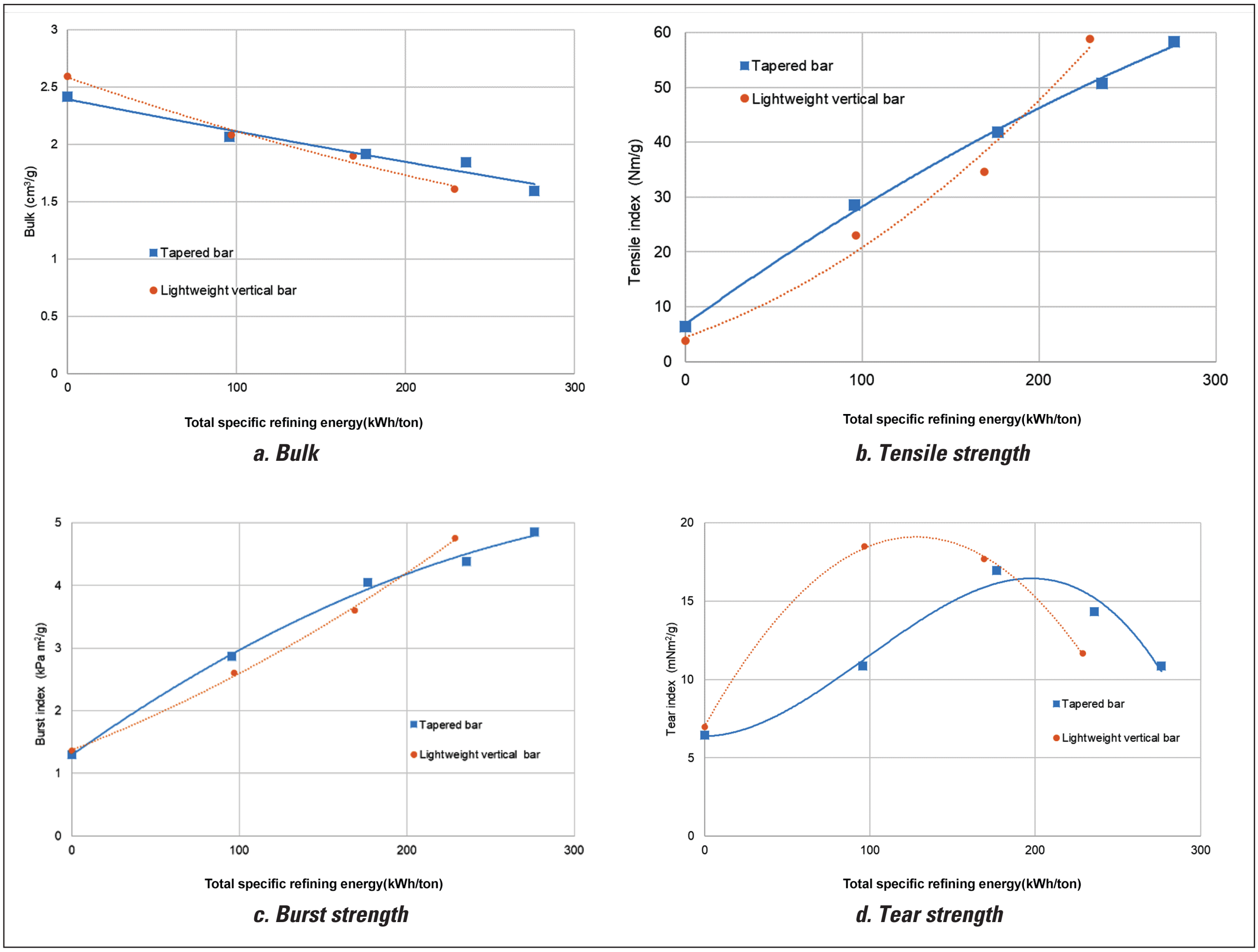
10. Comparison of mean fiber length (a) and fines contents (b) of pulp fibers refined by bar plates with and without a draft angle, respectively.

worn and the bar height is reduced during the continuous refining process, the sharpness and width of the bar edges for the lightweight plate remain constant, unlike the cast plate, so the plate can be used longer. The stainless steel alloy used to make vertical bars for the lightweight plate contains 0.42% carbon and 14% chromium, showing superior wear resistance than cast plates with the tapered bars containing 0.53% carbon [8]. The replacement cycle of the lightweight vertical bar plate with the same carbon/chromium materials currently used by Hansol Paper Co. Ltd. in Korea was longer than that of the cast plate having a tapered bar shape.

Change in pulp properties

The freeness of pulp is considered as a measure of the rate at which dilute fiber furnishes may be drained. Drainage rate is closely related to internal and external fibrillation of individual pulp fibers and generation of short fibers. It is used to determine or estimate a target level of refining for pulp or the ease of drainage of white water through the wet web, especially near the initial sections of the former. As shown in **Fig. 9a**, the refining energy required to achieve the same freeness level, 400 mL, achieved savings of up to about 23% when pulp fibers were refined by the bar fillings without a draft angle. In other words, the vertical bar plate had a much better advantage in reducing the refining energy, because the bar edges were much sharper than those of the trapezoidal bars.

Water retention value is a measure of the capacity of lignocelluosic fibers to hold water. It is closely related to internal and external fibrillation and fines [10]. As shown in **Fig. 9b**, regardless of the presence of the draft angle, the WRV of pulp fibers showed no significant difference during refining. **Figure 10** shows that the vertical bar plate in-



11. Change of physical properties of papers refined by bar plates with and without a draft angle, respectively.

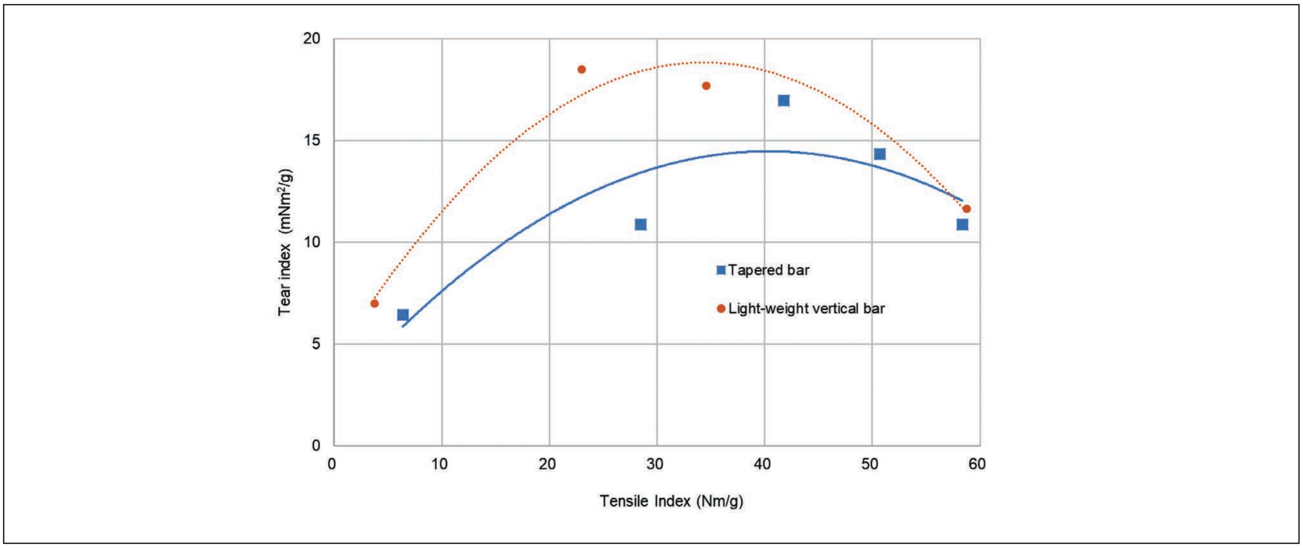
duced a little more fiber cutting, resulting in a little shorter fiber length than the trapezoidal bar plate. However, since the width of the vertical bar is wider than that of the tapered bar, more fibrillation was expected with fiber cutting. This could be easily seen through the change of fiber length and fines contents. The fines contents generated through the lightweight vertical bar plate during the refining process did not show much difference from the tapered bar plate. As a result, it was expected that faster reduction in freeness and more fibrillation from the lightweight vertical bar plate seemed to contribute to a faster development in fiber and paper properties compared to the trapezoidal bar plate. Another interesting point was that, despite the sharper bar edges of the vertical bar plate, there was no remarkable loss in fiber length compared to the trapezoidal bar plate. In general, it is well known that the greater the CEL, the more fibrillation of the pulp fibers is induced, which is well applied to hardwood kraft pulp. However, the coarse plate used for softwood kraft pulp with thick fiber walls and long fiber length showed different results from the fine bar plate. Softwood kraft pulp consumes more energy until it reaches the target freeness, so energy consumption can be reduced only when the pulp fibers are properly cut during refining. The lightweight plate with sharper edge was very positive for freeness drop, as the fiber shortening was more common than the cast plate with trapezoidal edges.

In conclusion, it was confirmed that the lightweight vertical bar plate for softwood pulp was very effective in reducing the energy required to reach the target freeness with sharper edges and wider bar width.

Change in paper properties

Figure 11 shows the effect of the refiner plate with different bar shapes on the physical properties of the paper. Except for tear strength, paper bulk, tensile strength and burst strength showed little difference according to bar shapes. Paper strength is greatly affected by the hydrogen bonding between neighboring fibers. It is well known that hydrogen bonding between fibers is greatly affected by the amount of fibrillated fibers and fines. However, more fines negatively affect the runnability of the paper machine, so it is preferrable to have more fibrillated fibers.

The lightweight vertical bar plates showed similar changes in strength development of paper during initial



12. Tear-tensile relationship of papers refined by bar plates with and without a draft angle.

refining compared to the trapered bar plates. As refining progressed further, however, the vertical bar plates began to have a greater impact on strength development. At this time, the paper bulk began to decrease, indicating that the interfiber bonds were improved. Tear strength is known to be greatly affected by fiber length. However, even though the fiber length was a little more shortened by the vertical bar plate during refining, the individual plates of different bar shapes showed a big difference. In the early stage of refining, the tear strength of paper by the vertical bar plate was higher than that by the tapered bar plate, but it began to decrease as the tensile strength by the vertical bar plate became larger. Initially, refining cellulosic fibers with a vertical bar plate reduced the fiber length slightly faster, but not enough to severely affect the tear strength (Fig. 10). As the refining continued, however, the reduction in tear strength occurred more rapidly than in the tapered bar plate, as the fiber length was reduced faster by the lightweight vertical bar plate.

In conclusion, it was found that the lightweight vertical bar plate was very effective for the development of most paper strengths without excessively sacrificing fiber length. **Figure 12** shows that the variation of tear strength aganst tensile strength was very different between the lightweight vertical bar plate and the tapered bar plate, but the tear strength decreased more steeply after prolonged refining. The lightweight vertical bar plate was very effective in the development of tear strength as tensile strength increased. However, as fiber length decreased more by the lightweight plate, the tear strength decreased more rapidly, despite the increase in tensile strength.

CONCLUSIONS

When refining softwood kraft pulp, the plate made using the sand casting method had several limitations in development of properties of pulp fibers and paper. The refiner plates made using sand casting should have draft angles to reduce the defect rate during the manufacturing process. Bar plates with a draft angle reduce the flow rate of pulp suspensions and negatively affect edge sharpness due to bar wear. As a result, the replacement cycle of refiner plates becomes faster, adding to the cost of paper mills. A new lightweight plate made using a bar insertion method into a plate base was developed by selecting aluminum alloy as the base material and a stainless metal alloy with high wear resistance as the bar material.

The vertical bar plate with sharp bar edges was highly effective in reducing refining energy for softwood pulp by reaching the target freeness faster than the casting bar plate. Pulp fibers refined using the vertical bar plate showed a little faster reduction in fiber length, but did not show significant differences in paper bulk, tensile strength, or burst strength from those refined using the tapered bar plate. However, in the case of tear strength, the fibers refined using the vertical bar plate showed faster strength development than did those refined using the tapered bar plate at the early stage of refining, and then the fiber length continued to shorten, resulting in lower tear strength.

Finally, the weight of the lightweight vertical bar segment was about half that of the casting bar plate and the sharpness of the bar edges was superior, which effectively contributed to the reduction of the refining energy and the improvement of paper strength without excessive loss of fiber length. **TJ**

ACKNOWLEDGMENTS

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education (grant number: 2017R1D1A3B04027967). The authors also thank the KOS1 officials for helping to manufacture the refiner plate.

LITERATURE CITED

1. Valmet, "Pulping developments," *Technical Paper Series*, Valmet, Espoo, Finland, 12 July 2013. Available [Online] https://www.valmet.com/globalassets/media/downloads/white-papers/board-and-paper-making/wppb_pulpingdevts.pdf <1April2021>.
2. Kay, I.M., *Eng. Cast. Solutions* 4(1): 48(2002).
3. Sama, S.R. and Manogharan, G.P., "Sand casting design rules," Pennsylvania State University, State College, PA, USA, 2017. Available [Online] https://sites.psu.edu/shapelab/files/2017/02/Trad_Casting_Rules_Santosh-2kkxcb8.pdf <1April2021>.
4. AFT, "Finebar refiner plates: Low-intensity refining at its finest," *AFT Catalog*, Aikawa Fiber Technology, Sherbrooke, QC, Canada, 2019.
5. J&L Fiber Services, "J&L refiner plates: Ultra-BarTM patterns with PowerCastTM technology," Valmet, Waukesha, WI, USA, 2006.
6. Andritz, "Energy-efficient fiber treatment with Durabond refiner plates," *Tech Talk* 34(2): 29(2016). Available [Online] <1April2021>. https://www.andritz.com/resource/blob/238890/ec187128ed38fead063fb15064adbadf/07-sp-2016-34-techtalk-data.pdf
7. Robinson, D., DeFoe, R., and Gooding, R., "Novel technology for ultra-low intensity refining," in *World Pulp & Paper 2010*, REM Productions, Milan, Italy, 2010, pp. 20-23.

ABOUT THIS PAPER

Cite this article as:
Gu, H., Min, B., and Lee, J-Y., et al., *TAPPI J.* 20(4): 241(2021). https://doi.org/10.32964/TJ20.4.241

DOI: https://doi.org/10.32964/TJ20.4.241

ISSN: 0734-1415

Publisher: TAPPI Press

About this journal

8. Lee, M-S., Kim, C-H., Lee, J-Y., et al., *J. Korea TAPPI* 51(5): 84(2019). https://doi.org/10.7584/JKTAPPI.2019.10.51.5.84.
9. Herbert, W. and Marsh, P.G., *Tappi* 51(5): 235(1968).
10. Mayr, M., Eckhart, R., Winter, H., et al., *Cellulose* 24(7): 3029(2017). https://doi.org/10.1007/s10570-017-1298-6.

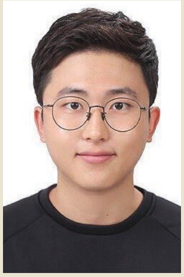
ABOUT THE AUTHORS

Because the refining process consumes the most energy in the papermaking process, this topic was chosen to find a way to reduce energy consumption. In our previous study, a vertical bar plate was manufactured by a casting method, but in this study, a technology to easily manufacture a lightweight vertical bar plate by a joining method of dissimilar metals was studied.

The most difficult aspect of this work was making the molten metal enter evenly during the pouring process to join different kinds of metals. However, this difficulty could be solved by gravity casting.

It was confirmed that the lightweight vertical bar plate can be easily replaced and has high refining efficiency. The refiner plate on the market until now has been quite difficult to replace due to its heavy weight, but the lightweight refiner plate is around half this weight and the bar shape is vertical, improving refining efficiency and extending the replacement cycle.

In paper mills, the use of lightweight vertical bar plates enables the purchase of plates at an economical price, and improvement in refining efficiency and paper quality can be expected. Our next goal is to introduce lightweight vertical bar plates to the global market.



Gu

Min

J-Y. Lee

Park

M-S. Lee

C-Y. Lee

Kim

Gu, M-S. Lee, and C-Y. Lee are graduate students in the Department of Forest Products at Gyeongsang National University, Jinju, Korea. J-Y. Lee and Kim are professors in the Department of Environmental Materal Science, and Park is advisory professor, Pulp & Paper Chemical Engineering, at Gyeongsang National University, Jinju, Korea. Min is representative director for KOS1 Inc., Gimhae, Korea. Email Kim at jameskim@gnu.ac.kr.