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Case Study of Fire Flame Resistance Improvement of a Plywood Board Coated with Paint Containing Added Rice Husk Amorphous Silica

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Authors' contributions

This work was carried out in collaboration among three authors. Author RS designed the study and performed the statistical analysis. Author MT wrote the protocol and first draft of the manuscript. Author CLV managed the analysis of the study and the literature searches. Three authors read and approved the final manuscript.

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ABSTRACT

Aims: Rice husks constitute an issue of concern for stakeholders interested in rice production; on the other hand, rice husk silica has been recognized as a valuable resource for industrial uses. Thermal insulation is a potential industrial benefit offered by silica. In this study, thermal resistance of rice husk silica, especially its resistance to fire flame, was investigated. It was found that rice husk ash should be ground for obtaining the desired effects.
Study Design: Time of burning out and the temperature increase rate were obtained for evaluating thermal resistance of rice husks. The former was the time from the launch of the fire flame to when the plywood board was burned. The latter was the temperature increase rate on the plywood board within 60 s.
Place and Duration of Study: Experiments were conducted at Toyama Prefectural University and the duration was between April 2016 and March 2017.

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Methodology: Paints that contained 0%, 5%, 10%, 15%, 20%, 25%, and 30% of rice husk ash (as is) by weight were prepared and one side of plywood boards (2.5 mm in thickness and 100 mm x 100 mm in area) were coated with these paints. After painting, the boards were dried for one day at ambient temperature. Each board was set in an upright position on a stable foundation and a fire flame (3.5 kW) was launched from a handheld burner from a distance of 0.1 m toward the board. The time from the launch of the fire flame to when the area demarcated by the red circle on the back side of the board was burned was measured and recorded.

Results: The following results were obtained in this study. Rice husk ash showed fire flame resistance. Ground rice husk ash was better than the as-is rice husk ash in terms of handling and offering fire flame resistance. The fire flame resistance increased as the ash contents increased up to 20% and it decreased drastically beyond 20%. The sample with 15% ash content showed the highest temperature resistance. The sample with 20% ash content showed resistance for the longest duration.

Conclusion: The fire flame resistance increased as the ash contents increased up to 20% in weight and decreased drastically beyond 20%. The optimal ash contents were in the range of 15–20%. Thus, rice husk silica can be a useful resource that provides further advantages to stakeholders involved in rice production globally.

Keywords: Rice husk silica; paints; thermal resistance; direct burning; temperature.

1. INTRODUCTION

Silica and thermal insulation are a very closed combination of jargons. Many researchers intending to achieve thermal insulation use silica because its thermal conductivity is extremely low, at about 0.01–0.03 W/m·K [1]. Two kinds of silica have been used for industrial thermal applications: chemical and biological silica. Tetramethyl orthosilicate (TEOS) is commonly used for obtaining chemical silica, whereas biological silica refers to silica obtained from rice husk ash. Thermal insulation using chemical silica has been used in the following scenarios: synthesis of polyurethane foam [1], development of a mathematical model for coating insulation [2], development of silica aerogels for solar applications [3], aramid pulp production [4], development of novel coating [5], life cycle assessment of hollow nanospheres [6], vacuum insulation panels [7], improvement of thermal properties of fibrous silica [8,9], and enhancement of chemical and thermal stability of magnetite nanoparticles [10]. Thermal insulation using biological silica has been achieved in production of cordierite [11] and forsterite [12] and for extruded and pressed thermal insulators [13]. Rice plants grow healthily by absorbing the dissolved silica in water in order to physically protect themselves from pests and severe weather conditions such as strong wind. Not only plants but also bacteria utilize the absorbed silica effectively for various reasons; for example, *Bacillus* spp. used the silica for acid resistance [14]. Because the absorbed silica is amorphous, it can have different functions in industrial use in addition to absorption, as a rubber filler, pigment, insulator, and so on [15]. Rice plants accumulate silica in high amounts in their own bodies, especially in rice husks, and the silica can be a valuable resource because of its various uses; thus, rice plants are termed a bio-ore of silica [16]. Rice husk silica is also used as an extender of paints [17–19]. Keeping in mind the insulation ability of silica and its use as paint extenders, promotion of the insulation ability of a common paint by the addition of rice husk silica was investigated. The purpose of this study was to investigate the effectiveness of rice husk amorphous silica added to paint in terms of the thermal resistance of a wooden material coated with the paint using a fire flame.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Rice husks

Rice husks used in this study were obtained from Koshihikari (*Oryza sativa L.*), one of the main rice cultivars grown in the area where Toyama Prefectural University is located.

2.1.2 Rice husk ash preparation

The rice husks were calcined at 800°C in an electric furnace (Koyo, KBF794N1, Japan) for two hours after washing the raw rice husks with acetic acid (5%).

2.1.3 Paint

An emulsion water-based paint (Hapio Select Milky White, Kanpe Hapio, Japan) was used.

2.2 Methods

2.2.1 Analytical methods

The oxide content of the rice husk ash was estimated by elemental analysis conducted using wavelength-dispersive X-ray fluorescence spectroscopy (WDX: PW2440, Spectris, United Kingdom). The crystallinity of rice husk silica was analyzed by X-ray diffraction (XRD: MultiFlex 40 kV, 30 mA, CuKα, 2θ: 5–80°, Rigaku, Japan). The surfaces of the rice husk ash particles were observed at macro- and micro-scales by a hand zoom recorder (Digital Micro Mobile Z, Biomedical Science) and by scanning electron microscopy (SEM, SSX-550, Shimadzu, Japan), respectively. Fixed carbon, ash, volatile matter, and moisture contents in the rice husk ash were determined following the Japan Industrial Standards (JIS) M 8812-8, M 8812-6.4.1, M 8812-7.2.4, and M 8812-5.2.4a, respectively [20]. The solubility of rice husk silica (S-silica) was measured following the Japan Standard Methods for determining solubility of silica in fertilizers (4.4.1.c) [21]. The total silica in rice husk ash (T-silica) was measured following modified Japan Standard Methods for calculating the total silica content in fertilizers (4.4.1.d) [21,22]. Particle sizes of ground rice husk ash was measured by Laser Diffraction Particle Size Analyzer (SALD-2300, Shimadzu).

2.2.2 Experimental methods

2.2.2.1 Time of burning out

Paints that contained 0%, 5%, 10%, 15%, 20%, 25%, and 30% of rice husk ash (as is) by weight were prepared and one side of plywood boards (2.5 mm in thickness and 100 mm x 100 mm in area) were coated with these paints. After painting, the boards were dried for one day at ambient temperature. The quantity of paint used for all samples were the same and thus only that of the rice husk ash used changed. Three boards plates were prepared for each percentage of ash content in the paint. Boards that had not been painted were used as controls. Each board was set in an upright position on a stable foundation and a fire flame (3.5 kW) was launched from a handheld burner (Power Gas Pro RZ-860, Shin-Fuji Burner) from a distance of 0.1 m toward the board (Fig. 1). The time from the launch of the fire flame to when the area demarcated by the red circle in Fig. 1 on the back side of the board was burned or turned from its original brown color to black was measured and recorded. The experiment was run in triplicate and mean values were used as representative data. The same experiments were performed with the rice husk ash that had been subjected to a grinding treatment to turn the ash into powder.

2.2.1.1 Temperature increase rate

Following the same procedure as above, the temperature increase inside the red circle on the back side of the plywood board was measured for 60 s using a radiation thermometer (AD-5614, A&D). For these experiments, only ground rice husk ash was used. The temperature increase rate was obtained by applying a linear regression to the temperature increase plots, and the slope of the linear regression was employed as the rate.

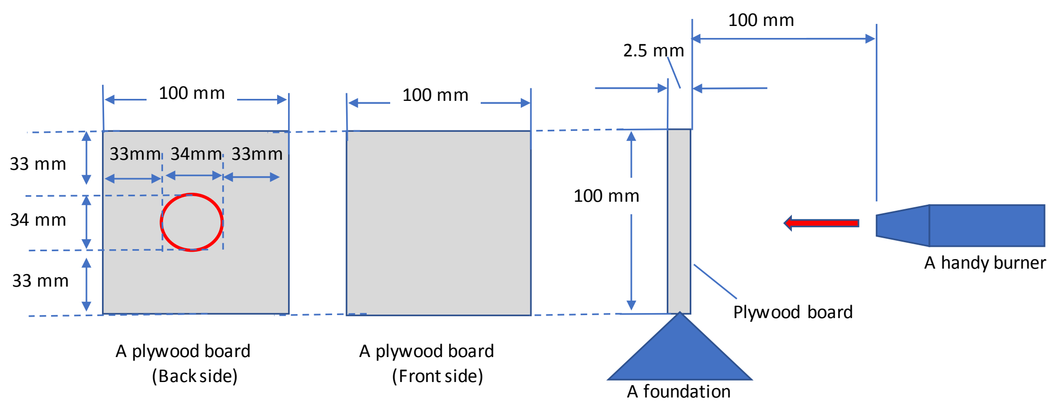

Fig. 1. Experimental design to determine the time for burning out

3. RESULTS

3.1 Physicochemical Properties of Rice Husk Ash

Four basic physical contents i.e., fixed carbon, volatile matter, ash, and water contents are shown in Table 1. The oxide content in rice husk ash was estimated by elemental analysis (Table 2).

Table 1. Four physical contents in rice husk ash in weight (%)

Fixed carbon	Ash content	Volatile matters	Water content
0.0	99.0	0.0	1.0

Table 2. Estimated oxide contents in rice husk ash in weight (%)

SiO_2 (T-silica)	P_2O_5	CaO	Fe_2O_3	K_2O
90.19	5.51	3.02	0.99	0.30

The total silica (T-silica) content was measured as 96% and the soluble silica (S-silica) content was 94%. The ash content consists of T-silica and other substances such as the oxides shown in Table 2. The T-silica in this study was amorphous, as explained below, and contained S-silica and non-S-silica.

Fig. 2 shows the X-ray diffractogram for the rice husk silica. As seen in the figure, the silica in the rice husk ash was not crystalline but amorphous as no peak was observed in the chart. T-silica, then, can be considered amorphous.

3.2 Morphology of Rice Husk Ash

Morphological observation was undertaken for two kinds of ash: rice husk ash as is and that ground into powder. Results for the former and the latter are shown in Figs. 3 and 4, respectively. In Fig. 3, the shape of rice husk was, unlike in Fig. 4, observed to have been retained and the ash seemed very bulky. Appearance specific gravity of the ash was 0.09 g/cm^3, whereas it was 0.4 g/cm^3 for the ground ash, whose particle size was less than approximately 45.6 ± 0.3 µm. Fig. 5 shows a SEM image for a rice husk. Comparison with Fig. 3 (a) shows that its shape was retained after burning.

3.3 Results for Time of Burning Out

The time of burning out as a function of the silica content in the paint is shown in Fig. 6.

Because the rice husk silica not subjected to grinding i.e., the rice husk ash as it is, was so bulky (appearance specific gravity: 0.09 g/cm^3), the 25 and 30% samples could not be prepared due to unbalanced or non-uniform spread of the paint on a board. Data for 25 and 30% of rice husk ash contents in the paint, therefore, could not be obtained. According to the figure, the board with only paint and no ash, i.e., the 0% sample, showed drastic increase in the fire flame resistance. For the ash not subjected to grinding, the optimal ash content was 10% and the fire flame resistant time was extended in about 7 s compared to the control 0% ash content sample. For the ground ash, these values were 20% and about 9 s, respectively.

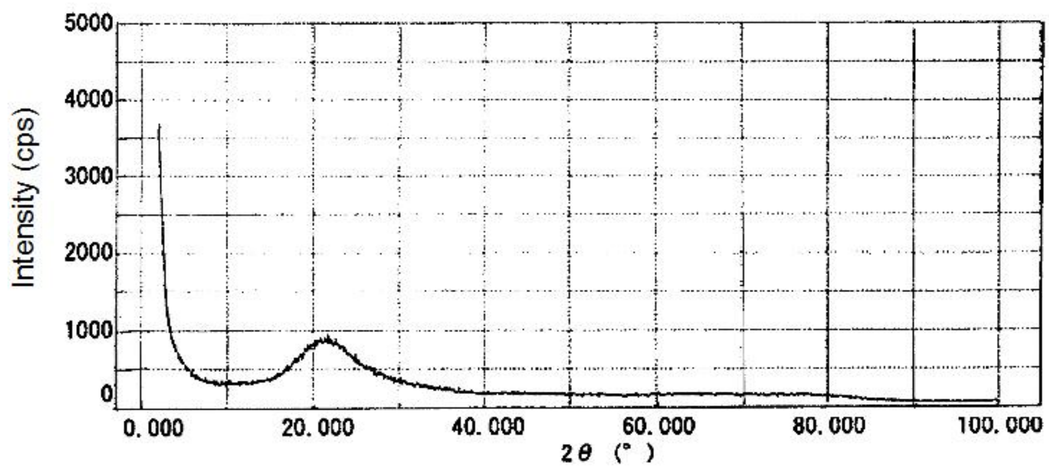

Fig. 2. XRD curve for the rice husk ash

Fig. 3. Close observations of rice husk ash (a: left) in individual and (b: right) in a flock

Fig. 4. Ground rice husk ash

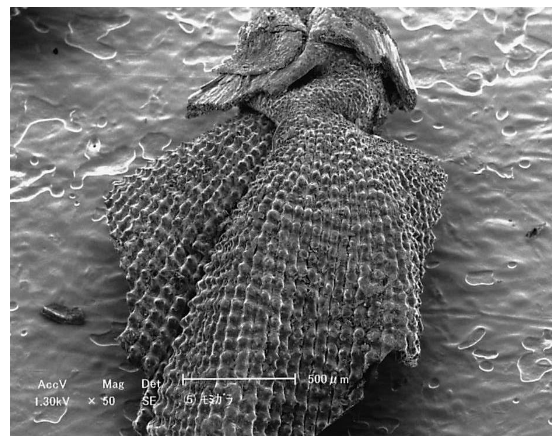

Fig. 5. SEM image for a rice husk

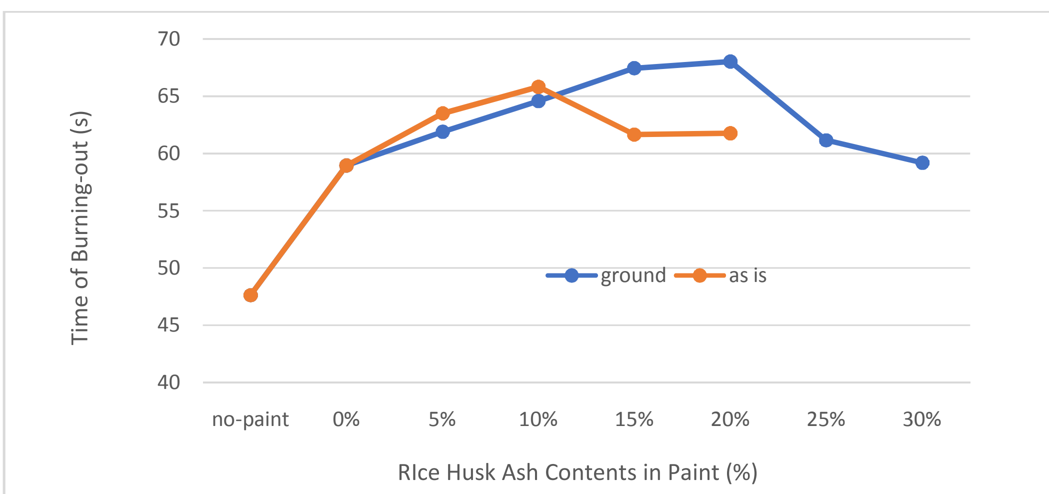

Fig. 6. Burning out time as a function of content of rice husk ash, as is and ground

3.4 Results for Temperature Change Rate

This experiment was performed using only the ground ash.

Thermal conductivity of the “no paint” sample or just a plywood board itself was around 0.13 W/m·K and this sample showed the highest temperature increase (Fig. 7) and highest temperature of 267.7°C after 60 s (Table 3). The fluctuation seen in Fig. 7 was strongly related to the temperatures reached after 60 s in Table 3. The longest time observed in Fig. 6 occurred when the ash content was 20% and showed one of the lowest temperature increase rates.

4. DISCUSSION

The ash content in this study, shown in Table 1, comprised T-silica, P_2O_5, CaO, Fe_2O_3, and K_2O (Table 2) and T-silica consisted of S-silica and non-S-silica. The fixed carbon content shown in Table 1 demonstrated that the rice husk ash produced in this study was completely white in color since the content value was 0.0%. Comparison of Fig. 3 (a) to Fig. 5 shows that as the rice husk burned, its original shape was maintained but the ash seemed to shrink and became rounded and narrower. Rice husk ash became fragile and could not retain its original shape if the rice husks were burned at low temperatures such as 500 and 600°C.

Regarding handling, the ash subjected to grinding was easier to handle since 25 and 30% content samples could be prepared: on the other hand, the 20% content sample showed the highest content for the ash that not subjected to grinding. Regarding fire flame resistance, the ground ash showed better performance than that not subjected to grinding. For both samples, for up to 10% content, the fire flame resistance showed almost the same trend. The 10% content sample showed the highest resistance to fire flame in the ash not subjected to grinding (time: 65.82 s); on the other hand, the 20% sample showed the highest resistance for the ash subjected to grinding (time: 68.02 s) (Fig. 6). The latter showed a 6% increase in time for which it exhibited fire flame resistance. The ground ash showed better performance in terms of handling and fire flame resistance. On mixing the rice husk ash with the paint uniformly and homogeneously, performance of the silica in the rice husk ash increased in terms of fire flame resistance and handling. There were several components in the ash (Table 2); however, silica mainly contributed to the performance as suggested by the quite low contents of other oxides.

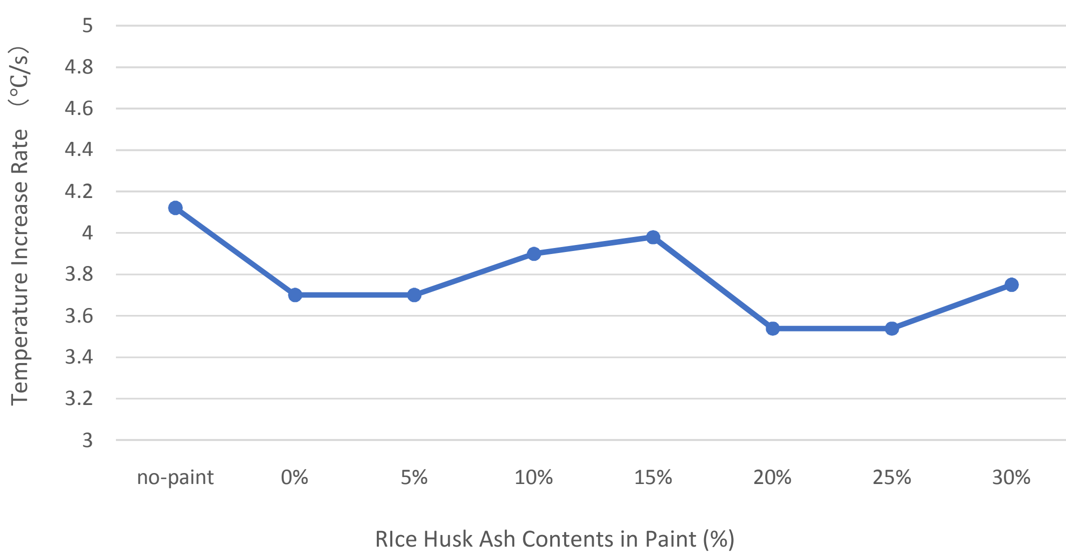

Fig. 7. Temperature increase rate as a function of rice husk ash content in paint

Table 3. Temperature of the red circle on the back surface after 60 s

Sample	No paint	0 %	5 %	10 %	15 %	20 %	25 %	30 %
Temperatures after 60 s (˚C)	267.7	235.3	232.7	251.3	254.3	222.7	222.0	241.7

Table 4. Final temperatures at burning out times

Samples	no paint	0%	5 %	10 %	15 %	20 %	25 %	30 %
Predicted Temperatures at Burning out times (˚C)	221.4	236.0	247.0	270.4	292.1	261.8	234.8	239.7

Regarding the temperature increase rate shown in Fig. 7, the rates for 10% and 15% contents of the ground ash increased although fire flame resistances increased, as well (Fig. 6). The reason for this was unknown. It might be attributed to the increase in porosity because of the bulky nature of rice husk ash. The fluctuation seen in Fig. 7 was closely related to the values in Table 3. The higher the temperatures reached after 60 s, the higher the temperature increase rates were. The sample with no paint (or the plywood board itself) led to the highest temperature (267.7°C). In Fig. 6, burning out was reached at 47.64 s for the "no paint" sample, and the board was, then, almost completely destroyed on burning for more than 60 s. According to Table 3, following the "no paint" sample, the sample with 15% ash content showed the next highest temperature, followed by the 10%, 30%, 0%, 5%, 20%, and 25% samples. As seen in Fig. 6, 1.90 s, 4.58 s, 7.44 s, 8.02 s, and 1.17 s were required after 60 s needed to reach burning out of the samples with 5%, 10%, 15%, 20%, and 25% contents, respectively. The 0% and 30% samples attained burning out earlier than 60 s. Table 3 shows temperatures for the region marked by the red circle on the back side of the plywood board after 60 s; the burning out times for the samples with 5–25% ash contents exceeded 60 s. The final temperatures were predicted by the first regression equations used for Fig. 7. The results are shown in Table 4.

According to the table, burning out was reached when the temperature of the surface reached over 220°C. The sample with 15% ash content showed the highest temperature, which was almost nearly 300°C. Since the burning temperature of the 0% sample was nearly 230°C, the plywood board with no paint coating was burned out at a temperature exceeding 230°C. Compared to the temperature of the sample with no paint, the painted plywood sample showed an increased fire flame resistance for up to 15°C of temperature increase. The optimal range of ash content was 15–20%. The 15% ash content sample exhibited the highest temperature increase and resisted the highest temperatures; on the other hand, the 20% ash content sample showed the slowest temperature increase rate and resisted the fire flame for the longest time.

5. CONCLUSIONS

The following results were obtained in this study:

- Rice husk ash showed fire flame resistance
- Ground rice husk ash was better than the as-is rice husk ash in terms of handling and offering fire flame resistance
- The fire flame resistance increased as the ash contents increased up to 20% and it decreased drastically beyond 20%
- The sample with 15% ash content showed the highest temperature resistance
- The sample with 20% ash content showed resistance for the longest duration
- The optimal ash contents were in the range of 15–20%.

Thus, rice husk is a useful material that could potential offer flame resistance and its ash offers even greater potential. Rice husk ash is one of the most effective and cheapest sources of silica. Case studies are required to determine further applications for the material, so that rice husk can be recognized as an even more useful resource and be recycled effectively.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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