Potential use of fully wood based sandwich panel for house component in Indonesia for disaster mitigation and rapid built: A review

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Abstract. Indonesia is one of the most disaster-prone countries on the earth. The disasters, particularly earthquake and landslide, usually result in loss and damage of human shelters. In regards to the housing, mitigation or disaster risk reduction by selecting proper house component materials is important. This paper discuss on fully wood based sandwich panel that could replace other materials for wall part of the house. The study shows that wood in various forms of derivative products remain preferable building material for housing due to several advantages. Wood-based sandwich panels with veneer or plywood at the facing (face/back) and solid or laminated board for the core are promising products to be used to rapid-built houses for the mitigation and reconstruction of disaster areas.

1. Introduction

Natural disasters are catastrophic events coming from atmospheric, geological, and hydrological origins (e.g. droughts, earthquakes, floods, hurricanes, landslides) that can cause fatalities, property damage and social environmental disruption [1]. Simply, Indonesian National Board for Disaster Management (BNPB) cited Indonesian Law Number 24 year 2007 defining that natural disasters are disasters caused by events or a series of events caused by nature such as earthquakes, tsunamis, volcanic eruptions, floods, droughts, hurricanes, and landslides [2]. Trend disasters will increase in future with increasing global climate change and environmental degradation [3]. However, most disaster occurrence cannot be predicted. The disasters have encouraged Indonesian people to accept the reality of coexistence with them. Earthquake disaster, for example, will likely occur in almost all regions in Indonesia.

Natural disasters often result in loss and damage. The biggest loss is - of course - the loss of life. Nevertheless, for those who survived, many victims also lost property and even their settlement. In the last three years (2018-2020), hundreds thousand houses loss and damage because of the disasters. In Lombok earthquake in 2018, the number of 83,392 units of houses were damage [4]. Throughout 2019 houses damaged by disaster as many as 72,992 housing units. It consisted of 15,747 units that were severely damaged (RB), 14,519 units were moderately damaged (RS), and 42,726 were slightly damaged (RR)[5]. Until mid-2020, the number of houses damaged by the disaster with the RB category amounted to 4051 units, RS by 2596 units and RR by 11,516 units [6]. The disasters lead to rise the need
of houses in Indonesia highly besides due to new household growth. Currently, the need for houses in Indonesia is quite high at 7.6 million units [7] with an annual demand rate of 800,000 units house [8].

Government initiatives to build low-cost and fast-built public housing need to be supported by stakeholders including material and technical sectors providers. Regarding the material for housing, wood still retains many advantages over more industrial building materials like concrete or steel. Not only do trees absorb CO2 as they grow, they require much less energy-intensive methods to process into construction products [9]. As wood is the only significant building material that is grown, we have a natural inclination that building in wood is good for the environment [10]. Not only from environmental aspects, the construction of using wood as a building material is reliable, even for tall building. According to [10] timber is particularly structurally efficient material in structures, or parts of structures, in which a high proportion of the load to be resisted is the self-weight of the structure itself.

Although potentially available, wood has limited characteristics, especially timber from plantations and community forests which are dominated by fast growing species. They have some weaknesses i.e. small dimensions (diameter) and less in strength, durability as well as its stability. To overcome the weaknesses of these properties, it is necessary to input technology in the form of engineered wood and lignocellulosic materials, which include sandwich panels and composite beams that can withstand flexible loads.

There are still limited studies on wood-based sandwich panels (completely or partially consisting of wood materials) as transformable house constituent; however, several research projects have focused on design of facade panels and deck structures for traditional houses [11]. This paper reviews potential use of fully wood-based sandwich panel for house component for disaster mitigation with rapid rebuilt in Indonesia.

2. Disaster mitigation and housing

Due to its geographical and geological condition, Indonesia is one of the most disaster-prone countries on the earth [3,12]. Over the last 30 years, this tropical country has experienced an average of 290 significant natural disasters every year [13]. Almost all of type natural disasters occur in Indonesia, including volcanic eruptions, earthquakes, flooding, forest fires, and tsunami which have claimed lives and devastated communities in Indonesia. According to [14], the most frequent disasters in Indonesia are floods and earthquake.

The recent disasters that caused big loss and damage were summarized by the Center for Excellence in Disaster Management and Humanitarian Assistance (CFE-DM) [15] i.e. cyclone Cempaka on November 2017 in East Java and D.I. Yogyakarta provinces; volcanic eruption on August 2017 of Mt. Agung in Bali; earthquake on December 2016 in the Pidie Jaya District, Aceh Province; floods and landslides on May-July 2016 in the provinces of Kalimantan (South, West, and Central), Bengkulu and Gorontalo; floods and landslides on August-October 2016 in Ende, East Nusa Tenggara Province; floods and landslides on November 2015 in West Java, Central Java, West Sumatra and Jakarta; drought in 2015-2017 in eastern Indonesia; floods and landslides on November-December 2014 in multiple parts of Nanggroe Aceh Darussalam; Mt. Kelud Volcano Eruption on February 2014; Mt. Sinabung Volcano Eruptions on September 2013-November 2015; floods and landslides on November 2013-January 2014 and 2013 in Jakarta; and Lombok earthquake in 2018.

In general, earthquakes are nature's most unpredictable and one of the most devastating natural disasters. When high intensity earthquakes occurs they can cause thousands of deaths and billions of dollars in damaged property [16]. Since 1900 onward, [17] recorded that there are around 100 key earthquakes (or around 1% of damaging earthquakes) have caused around 93% of fatalities globally. In Indonesia, the total of 174,900 unit of houses were damaged with severe, moderate and slight damage categories [4-6]. While disasters are unavoidable and unpredictable, the elimination of all risk is also impossible. In spite of the increasing frequency and severity of the catastrophes that strike humankind, it would be better to increase possibility prevent and mitigate the effects of disasters [19].
Further, the literature on hazards and disasters is full of technical terms. Two mitigation and preparedness are commonly used to categorise the main methods of protecting communities against hazards and disasters. ‘Mitigation’ can be defined as any action to minimise the impact of a potential disaster; ‘preparedness’ refers to specific measures taken before a disaster strikes, usually to issue warnings, take precautions and facilitate a rapid response [19]. When a big earthquake attack a house, many possibilities can happen. If the house strong enough, then nothing happen and loss of human lives can be avoided. However, if it is in very bad condition as many houses on the earth, it can be broken or some of material waste could be felt down. It can be dangerous to the human under it. However, there is no building can be made 100% safe against earthquake forces. Instead buildings can be made earthquake resistant to certain extent depending upon serviceability requirements. Earthquake resistant design of buildings depends upon providing the building with strength, stiffness and inelastic deformation capacity which are great enough to withstand a given level of earthquake-generated force. This is generally accomplished through the selection of an appropriate structural configuration and the careful detailing of structural members, such as beams and columns, and the connections among them [20].

3. Wood based material for housing development

Forest serves a wide range of socio-economic and ecological benefits in our live [21,22]. It produces the most important renewable sources that can be utilized for building materials and other composite products [23]. Wood have been used for many years in Indonesia to build traditional houses [24-35]. Further, the environmental awareness has led modern community to utilize timber instead of the more energy intensive materials [23,36-38]. The recent study called the wood-based modern house as the environmentally and energetically efficient construction [37].

Previous study reported that the utilization of wood as a construction material in the New Zealand decreased about 20% in fossil fuel energy and 20% in atmospheric carbon emissions [36]. Nevertheless, the escalated wood utilization for construction material should be also coined with the sustainable timber stock [36]. This is inline with Ramage [10] who stated the urgency of the use of global certification schemes to ensure the sustainable use of legal wood.

The production trend of roundwood in Indonesia is increasing. It was recorded that the roundwood production from 2016 to 2018 was 23.12 millions m³, 42.25 millions m³ and 55.52 millions m³, respectively [39-41]. It suggests that timber material is still demanding. However, the supply of large diameter timber is limited and therefore the utilization of wood-based composite products is inevitable. Wood-based composite product is defined as a multilayers materials that adhered together [42].

Varied technologies introduced in the wood composite manufacturing escalate its dimensional stability and durability, and give more homogenous mechanical properties [10]. Furthermore, [10] listed engineered timber products that can be produced from softwoods, such as glulam, Laminated Veneer Lumber (LVL), structural veneer lumber or beam, Cross Laminated Timber (CLT), I-joists, structural insulating panels and brettstapel. The application of these products are for interior and exterior usages: roof, wall, floor, beams, columns, cord, joist, long span and high loading of beam [10].

The wood-based modern house made of prefabricated sandwich panels was resulted in the greater life-cycle time assessment in contrast to a traditional masonry construction system [37]. It was argued that the use of wood-based composite product as a building material is such a promising way to an efficient and sustainable housing development.

4. Sandwich panel: a promising material for quick-built house

Sandwich panels is a layered construction formed by bonding two thin facings to a thick core [43]. Sandwich panels have become more common in different engineering, including house buildings, and used either in structural or non-structural components in construction. Sandwich structures are usually made from two thin face sheets with high stiffness and strength, and a compliant and light-weight core that maintains the distance between the faces and sustains deformation, often with insulation properties.
By using variation of the material and thickness of core and face sheets, it is possible to obtain sandwich structures with different properties and performance [44]. Conventionally, sandwich panels are manufactured from steel, stainless steel and aluminium which are often used for face material. In many cases it is also suitable to choose fibre- or glass- reinforced plastics as face materials [45]. The core can be made of a weak and low density material, separates and stabilizes the thin facings and provides most of the shear rigidity of the sandwich construction. Selecting properly of materials for facings and core, constructions with high ratios of stiffness to weight can be achieved. As a crude guide to the material proportions, an efficient sandwich is obtained when the weight of the core is roughly equal to the total weight of the facings [43].

Traditional housing construction industry usually relies on conventional well known building materials, like timber, concrete and steel due to attractive price and available design and manufacturing technologies. However in rapidly grooving market of transformable houses and shelters application of pre-fabricated wood based sandwich panels could provide significant savings on transportation and installing [46]. Regarding the economical consideration, Moody et al. [43] explained that sandwich construction is also economical because the relatively expensive facing materials are used in much smaller quantities than are the usually inexpensive core materials. The materials are positioned so that each is used to its best advantage.

Wood-based sandwich panels with low density fiberboard core were developed for structural insulated walls and floors, with different face material, panel thickness, and core density. The panel was found to be closest to the optimum design, which meant that its core and face thickness were optimum for stiffness with minimum density. The panel also provided enough internal bond strength and an excellent dimensional stability. The panel was the most feasible for structural insulation use with the weight-saving structure [18]. Thermal insulation and warmth-keeping properties of thick plywood-faced sandwich panels with low-density fiberboard Plywood Faced Sandwich (PSW), which were developed as wood-based structural insulation materials for walls and floors. The PSW provided thermal insulation properties superior to those of the boards and in terms of warmth keeping properties were greatly advantageous over the insulators. These advantages were due to the moderate densities of PSW panels. The PSW panel with sufficient thickness showed remarkably improved thermal resistance compared with those of the boards [47].

| No | Advantages | Sandwich panels (general) | Wood based sandwich panels | References |
|----|------------|--------------------------|--------------------------|------------|
| 1  | provide significant savings on transportation and installing | √ | √ | [11,43,46,52] |
| 2  | decorative effects | √ | √ | [43] |
| 3  | wide range of light material can be used for the core | √ | √ | [43] |
| 4  | wide range in density can be produced | √ | √ | [43] |
| 5  | higher specific stiffness compared to a solid plywood board | x | √ | [11] |
| 6  | better thermal insulation properties | x | √ | [18,47] |
| 7  | flexural and shear stiffness can be easily achieved by increasing the core thickness with little increase in weight | x | √ | [11,18,49] |
| 8  | renewable resources | x | √ | [48] |

Remarks: √ = applicable; x = not applicable
We can discuss further on each advantage of general sandwich panel. However, in this section the authors would like to elaborate on the most comparative advantage fully wood based sandwich panels compared to other materials of which can be applied for the wall parts of a house buildings. That is wood based sandwich panels that are made from veneer or plywood at the facings and solid or laminated board. In general, brick (bata merah) and concrete brick (batako) are most used traditionally for wall part of houses built in Indonesia. Nowadays, Aerated/Autoclaved Lightweight Concrete (ALC) (batar ringan) emerge to be used in house development in Indonesia (Table 2 and Figure 1).

Table 2. Common materials used for wall houses

| No | Wall material                        | Size (mm)     |
|----|---------------------------------------|---------------|
| 1  | Brick                                 | 25 x 12 x 5   |
| 2  | Concrete brick                        | 40 x 20 x 10  |
| 3  | Aerated Lightweight Concrete/ALC      | 60 x 20 x 10  |

Figure 1. Common materials used for wall houses in Indonesia: (a) brick; (b) concrete brick; (c) lightweight brick/ALC

To build a type-36 house with two bedrooms, for instance, the number of bricks needed from those three types of them are obviously different because the difference of their sizes. The type-36 houses with two bedrooms generally have a total wall area of 154 m². Comparison of the amount of each brick needed, is presented in Table 2. In terms of the completion speed of the wall construction, the three types of material will definitely give a different speed. Building a wall using ALC will be faster than that using concrete brick, and using concrete brick will be faster than using brick. Now, imagine to build a house wall, we will replace the three types of bricks above with all-wood sandwich panel (Figure 2) with the size of 2440 x 1220 x 36 mm. Therefore, this means that using wood based sandwich panel composites can complete building the wall much faster than using all types of bricks. We made a simulation of the installation speed of each type of wall materials as presented in Table 3.

Figure 2. The design of wood based sandwich panel
Table 3. Simulation of installation speed comparison of four types of wall materials

| No | Wall material                      | Size (mm)          | B (pcs/m²) | L (m²) | S (tu/m²) |
|----|-----------------------------------|--------------------|------------|--------|-----------|
| 1  | Brick                             | 250 x 120 x 50     | 70         | 154    | 1.000     |
| 2  | Concrete brick                    | 400 x 200 x 100    | 12         | 154    | 0.171     |
| 3  | Aerated Lightweight Concrete/ALC   | 600 x 200 x 100    | 7          | 154    | 0.100     |
| 4  | Wood based sandwich panel         | 2440 x 1220 x 36   | 0.34       | 154    | 0.005     |

Remarks: B = the number of materials needed (pcs) per square meter wall; L = total area of wall of type-36 house; S = installation speed unit per square meter wall; pcs = pieces; tu = time unit.

Table 3 shows a simulation of the installation speed of four types of wall materials. The calculation based on a type-36 house with two bedrooms, one bathroom/toilet, kitchen, and living room, generally the total of wall area for this house type is 154 m² [50,51]. If using brick with 70 pcs bricks per square meter wall, we could complete the work for building the wall by 1.000 time unit, so when using concrete brick and ALC, the work would be finished faster, within 0.171 and 0.100 tu/m². Surprisingly, wood based sandwich panel could accomplish extremely fast. It’s 0.005 tu/m² or only 5‰ compared to brick. In a house being developed, wood sandwich panels can be applied following the design as shown in Figure 3.

![Figure 3](image_url)

Figure 3. The design of wood-based sandwich applications: wall and beams structure (a); wall with fully-wood sandwich panel (b) interior views (c and d)

5. Conclusion
Wood in various forms of derivative products remain preferable building material for housing due to several advantages. Wood-based sandwich panels with veneer or plywood at the facing (face/back) and solid or laminated board for the core are promising products to be used to fast-built houses for the mitigation and reconstruction of disaster areas.
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