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Panel products made of oil palm trunk bagasse (OPTB) and MMA (Methyl methacrylate)-styrofoam binder

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ABSTRACT
The waste product left over from pressing or extracting oil palm trunk (OPT) for sugar purposes is known as oil palm trunk bagasse (OPTB). This residue contains mainly vascular bundles and small amount of parenchyma. These materials are potentially utilized for making panel products such as particleboard (OPTB-particleboard). Objective of this study was to evaluate physical mechanical properties of OPTB-particleboard. For preserving the durability, this work was intended to apply 15% mixture of methyl methacrylate (MMA) cured with Styrofoam as the binder with a ratio (w/w) of 3:1. OPTB-particleboard was made according to the Japanese Industrial Standard (JIS A5908: 2003) with a target density of 0.75 g/cm^3 and dimensions of 25 x 25 x 1 cm^3. Hot pressing was a condition set at a pressure of 30 kg/cm^2 and a temperature of 160 °C for 15 minutes. Physical and mechanical properties were tested according to JIS A 5908:2003 standard. The results showed that physical and mechanical properties of the OPTB-particleboard did not meet the standard. The characteristics of OPTB still easily absorb water even though MMA-Styrofoam should hinder water ingress. Additionally, the poor quality of the OPTB-particleboard was primarily due to the binder's inadequate composition. Optimum values reached when IB, MOR, and MOE were 0.026 MPa, 6.69 MPa, and 892 MPa, respectively. Based on the analysis of variance, it can be concluded that there is no influence on the bottom, middle and upper parts of the origin of the OPTB except for the MOR.
Keyword: MMA, Oil Palm Trunk Bagasse, Particleboard, Styrofoam

1. Introduction

The production of composite products such as plywood, particleboard, and fiberboard as construction, building components, and furniture has increased [1]. However, the availability of raw materials in the forest was limited due to deforestation. Deforestation in Indonesia from 2018 to 2019 was 0.46 million ha [2]. This phenomenon makes the shortage of wood raw materials a problem that must be faced by the timber industry in Indonesia, especially the furniture industry. Alternatives to replace wood as the primary raw material are essential concerns utilizing other lignocellulosic materials.

One of the lignocellulosic materials that are readily available is oil palm trunks. As one of the largest producers and consumers globally, Indonesia supplies approximately half of the world's palm oil needs. The area of oil palm plantations in Indonesia in 2019 reached 14.32 million ha. This area has increased from 2017 (12.3 million ha) and can continue to grow [3]. Within 25 years, the oil palm plantation area was rejuvenated through replanting activities to replace unproductive oil palm. Replanting produces the main waste in the form of oil palm trunks. Oil palm trunk waste is currently only handled by burning, which can pollute the air. In addition, allowing the waste of oil palm trunks resulting from replanting causes problems for new oil palm plants, namely becoming a nest of insects, pests and rats [4].

Oil palm trunks can be used as wood products such as plywood [5], particleboard [6], composite-plywood [7], laminated board [8], and hybrid plywood biocomposites [9], and fiberboard [10]. Moreover, oil palm trunks can be used for bioplastic materials [4,11,12]. Cahyaningtyas et al. [4] studied modifying oil palm trunk starch to improve starch's chemical and thermal properties as a raw material for bioplastics. The process extraction of starch from oil palm trunks for bioplastics resulted in oil palm trunk bagasse (OPTB). The OPTB has not been utilized and can be used as innovative products such as particleboard (OPTB-particleboard).

On the other hand, styrofoam, known as expanded polystyrene, is used worldwide for various purposes, including thermal insulation, packing, coffee cups, fabrication of car parts [13]. The disposal of these products creates environmental pollution because of their non-degradable nature [14]. The utilization of styrofoam was successfully developed as a binder for the composite product [13-15]. In addition, polystyrene-treated wood had much higher resistance than untreated samples to subterranean termite attack in a field test [16]. Styrofoam can be copolymerized with other monomers such as methyl methacrylate (MMA) was combined [17].

In this study, MMA and styrofoam were used as binders OPTB-particleboard. The use of MMA is expected to improve the quality of OPTB-particleboard, especially its durability as previous other studies carried out [18,19]. In contrast, the use of styrofoam is expected to improve the quality of OPTB-particleboard, especially the physical and mechanical properties of the OPTB-particleboard and help reduce styrofoam waste in the environment [13]. Objective of this study was to evaluate physical and mechanical properties of OPTB-particleboard bonded by methyl methacrylate (MMA) cured with Styrofoam binder.

2. Method

2.1. Materials

The material used in this study is the oil palm trunks bagasse (OPTB) derived from the starch extraction of the OPT. The equipment used to extract and resulted OPTB were presented in Figure 1 including samples originated from the bottom, middle, and upper part of the trunk. Intention to differentiate among parts of the origin of OPTB was to investigate whether position within the trunk influence the properties of resulted OPTB-particleboard. Therefore, here mixture of the three was included as the comparison. The oil palm trunk was extracted from an oil palm plantation in Jasinga, Bogor, West Java. Mixture of commercial methyl methacrylate (MMA) UN 1247 monomer stabilized (Lotte Chemical, Indonesia) and styrofoam (3:1 w/w) were used as binders. The styrofoam used is the waste for shock absorbers in electronic devices.

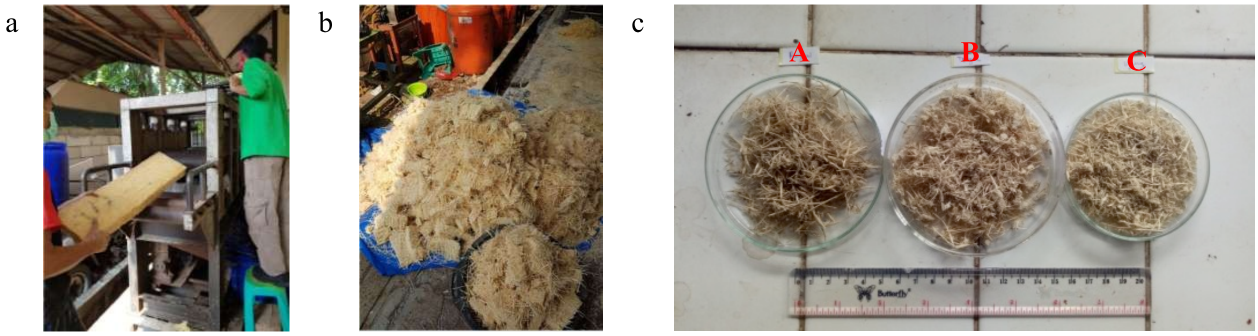

Figure 1. A crusher, an equipment to extract starch from oil palm trunk, developed by Indonesian Science Institute (now National Research and Innovation Agency (BRIN), was used in this study (a); resulted OPTB (b); and dried OPTB as the raw material in this study originated from the bottom (A), middle (B), and upper (C) part of OPT.

2.2. Production OPTB-particleboard

OPTB-particleboard was made according to the Japanese Industrial Standard (JIS A5908: 2003) with a target density of 0.75 g/cm^3 and dimensions of 25 cm x 25 cm x 1 cm (length x width x thickness). The binder used is a mixture of MMA and Styrofoam with a weight ratio (w/w) of 3:1. Before mixing, the styrofoam was cut into small pieces with 1 cm x 1 cm to facilitate the mixing process. Styrofoam that has been cut into small pieces is then put into a container and dissolved with MMA solution, then stirred gently until homogeneous by sight alone. A mixture of MMA and Styrofoam at 15% of the total weight dried was applied to the OPTB-particleboard. Hot pressing is carried out at a pressure of 30 kg/cm2 and a temperature of 160 °C with a total pressing time of 15 minutes.

The OPTB-particleboard was conditioned for 14 days at room temperature. Then the OPTB-particleboard were cut into test samples base on JIS A 5908: 2003. Each test sample was tested with three repetitions for a total of 16 boards. As a comparison, OPTB-particleboard bonded with 10% phenol-formaldehyde (PF) adhesive (purchased from PT Pamolite Adhesive Industry, Probolinggo, East Java, Indonesia) with 60% solid content was utilized for references. The procedure followed the same method of making the OPTB-particleboard bonded by MMA-Styrofoam as well as the same basic raw materials (bottom, middle, upper, and mixture of the three) of OPTB.

2.3. Physical and mechanical test OPTB-particleboard

Physical and mechanical properties were tested according to JIS A 5908-2003 standard. The physical properties tested were density, moisture content (MC), water absorption (WA) and thickness swelling (TS). Meanwhile, the mechanical properties consist of modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB). OPTB-particleboard density was tested using a sample 10 x 10 x 1 cm^3. Samples were weighed in an air-dry state and measured for length, width, and thickness. The MC of OPTB-particleboard was calculated the difference in weight before and after the oven 103 °C. The WA of OPTB-particleboard was carried out by measuring the difference in weight before and after immersion in cold water for 24 hours. In addition, TS of OPTB-particleboard has measured the difference in thickness before and after immersion in cold water for 24 hours.

MOE of OPTB-particleboard was measured simultaneously with a MOR testing 20 x 5 x 1 cm. The sample was tested using Universal Testing Machine (UTM) (Tensilon RTF-1350, A&D Company, Tokyo, Japan) with a loading speed of 10 mm/min and a span of 15 cm. The IB of OPTB-particleboard measuring 5 cm x 5 cm x 1 cm was glued between two wooden blocks using an epoxy adhesive and allowed to dry for 24 hours. Then the sample is tested by being pulled perpendicular to the surface with a loading speed of 2 mm/min.

3. Result and Discussion

3.1. Appearance

The appearance of the OPTB-particleboard is presented in Figure 1. The OPTB-particleboard bonded with MMA-Styrofoam did not show any discolouration. Meanwhile, OPTB-particleboard bonded with PF showed a reddish-brown stain. The use of MMA-Styrofoam as a binder OPTB-particleboard is possible and results in a clean performance. This is advantageous if the OPTB-particleboard is used for raw materials for interior purposes such as furniture, insulation, or light construction. Unlike OPTB-particleboard bonded with PF adhesive, an absolute coating is given to cover the stains. Colour performance is one of the evaluation materials consumers uses of wood products [20].

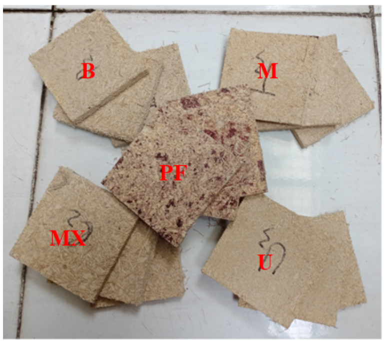

Figure 2. The appearance of OPTB-particleboard under various positions (U: upper; M: middle; B: bottom; MX: mixed) bonded with MMA-Styrofoam binder and PF adhesive.

3.2. Density

Even though the density of OPTB-particleboard bonded by MMA-Styrofoam ranged from 0.52-0.61 g/cm^3 and met the JIS A 5908-2003 standard which requires a density value of 0.40-0.90 g/cm^3 (Figure 3), the target density was not achieved. This condition because of internal force derived from the OPTB-particleboard after hot pressing. After exposing high pressure when hot pressing, the OPTB-particleboard reacts as called “spring back” which means the particleboard forces to return-back to initial condition before pressing. The density value increases from the bottom to the upper and decreases again in the three mix positions. The highest density was found at the upper, with an average value of 0.61 g/cm^3. Meanwhile, the lowest was found at the bottom, with an average value of 0.52 g/cm^3. As depicted in Figure 1, the middle and upper of the particles are finer in size than at the bottom. The particle geometry affected some of the basic properties of panels made from oil palm trunks [21]. Analysis of variance indicates that the position of the trunk does not have a significant effect on the density of the OPTB-particleboard.

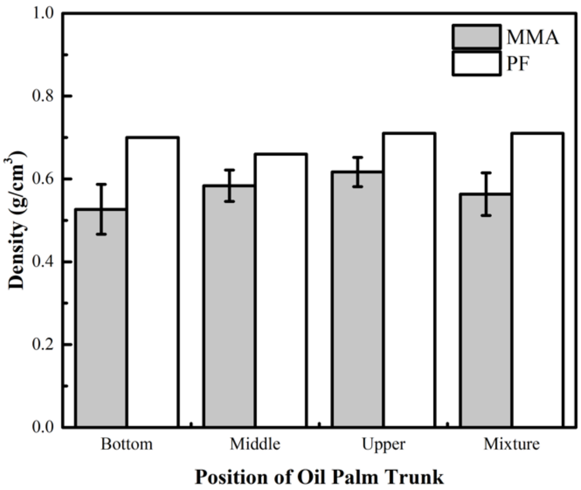

Figure 3. The density of OPTB-particleboard at different positions of oil palm trunk.

OPTB-particleboard bonded with MMA-Styrofoam has a smaller average density value than OPTB-particleboard bonded with PF. The average density value of OPTB-particleboard bonded with PF at each position of the trunk section is 0.70 g/cm^3 and relatively stable. These phenomena are due to the PF adhesive's high wettability that fills the particleboard cavity. PF adhesive is an adhesive used in the particleboard industry that has the advantage of good adhesive properties [22].

3.3. Moisture content (MC)

Based on the test results, the average MC of OPTB-particleboard bonded with MMA-Styrofoam ranged from 6.4%-8.8%, as shown in Figure 4. The MC value increased from the bottom to the upper and then decreased in the mixed position. Analysis of variance stated that the position of the trunk did not have a significant effect on the MC of the OPTB-particleboard. The highest MC of OPTB-particleboard was found on the upper position (8.83%), while the lowest was in the bottom (6.4%). The MC of the OPTB-particleboard produced has met JIS A 5908-2003 standard (5-13%). The condition of MC of the OPTB-particleboard bonded with MMA-Styrofoam was like the previous work [6] which applied liquified adhesive, urea-formaldehyde resin, or isocyanate on wood-particleboard. In addition, the comparison OPTB-particleboard bonded PF adhesive has an MC value that fluctuates between 8.1-11.1%, relatively higher than the OPTB-particleboard bonded with MMA-Styrofoam. In this case, MMA-Styrofoam binder within the OPTB-particleboard could better hinder the infiltration of water ingress from the environment compare to the PF does.

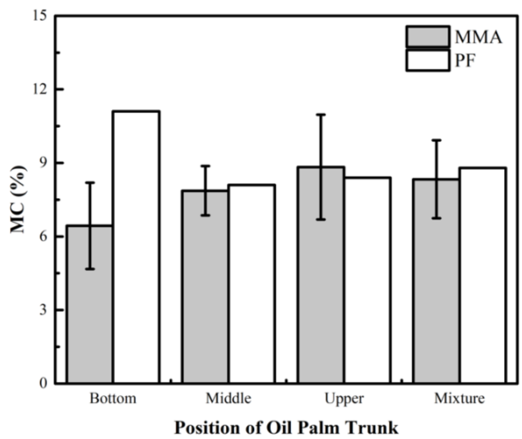

Figure 4. The MC of OPTB-particleboard at different positions of oil palm trunk

3.4. Water absorption (WA)

Figure 4 shows the WA of OPTB-particleboard bonded with MMA-Styrofoam after immersion for 24 hours. Figure 4 shows that WA decrease from bottom to upper. The high WA value is due to the very hygroscopic of the oil palm trunk. The structure of the oil palm trunk contains cellulose and hemicellulose, and other compounds that are very easy to absorb water [23]. The average WA ranged from 276.93% to 297.53%. The lowest WA was obtained at the upper, while the highest value was obtained at the bottom. Compared to OPTB-particleboard bonded PF adhesive, OPTB-particleboard bonded MMA-Styrofoam has a greater WA value. This is because PF adhesive has advantages in resistance to water treatment and moisture [24]. The analysis of variance results stated that the position of the trunk had no significant effect on the WA of the OPTB-particleboard.

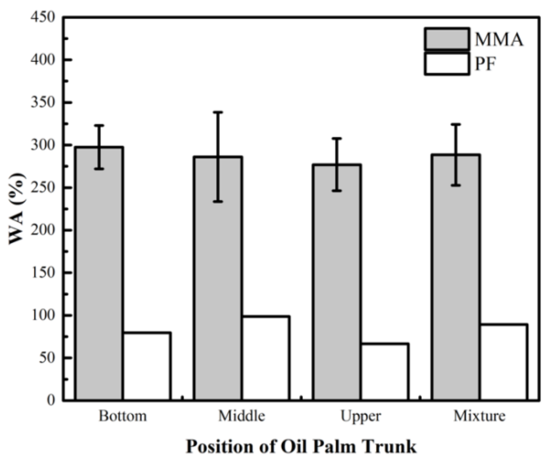

Figure 5. The WA of OPTB-particleboard at different positions of oil palm trunk.

3.5. Thickness Swelling (TS)

The average TS of OPTB-particleboard bonded with MMA-Styrofoam ranged from 120.38 % to 156%, shown in Figure 6. The highest TS OPTB-particleboard occurred in the mixed positions with an average TS of 156%, while the lowest TS was obtained at the upper of 120.38 %. As shown in Figure 6, the TS of OPTB-particleboard fluctuates due to the oil palm trunk's high hygroscopic and inhomogeneous size factor. The TS of particleboard influence by raw material type [21,25]. The TS of OPTB-particleboard has not met the JIS A 5908-2003 standard, which requires the swelling of 12%. Meanwhile, OPTB-particleboard bonded with PF has a much smaller value at the bottom, middle, and mixture than OPTB-particleboard bonded with MMA-Styrofoam. Analysis of variance stated that the position of the trunk had no significant effect on the TS of the OPTB-particleboard.

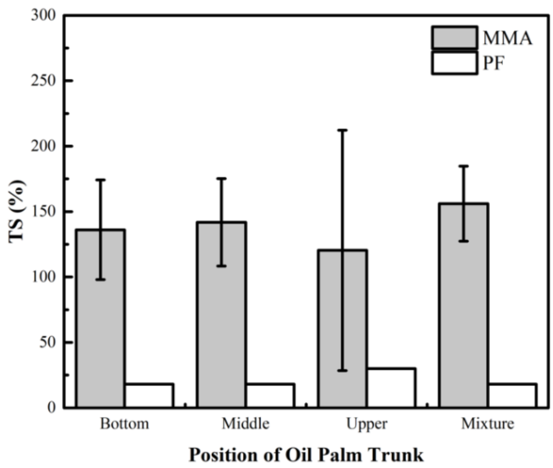

Figure 6. The TS of OPTB-particleboard at different positions of oil palm trunk.

3.6. Modulus of elasticity (MOE)

Figure 7 shows the MOE value of OPTB-particleboard bonded with MMA-Styrofoam. MOE OPTB-particleboard bonded with MMA-Styrofoam ranged from 364-892 MPa. The highest MOE was found at the upper, while the lowest was found at the bottom. All MOE values of OPTB-particleboard do not meet JIS A 5908-2003, which requires a MOE value of 2000 MPa. The low value of MOE due to the raw material used for oil palm trunks contains pith properties. According to Mawardi et al. [26], the MOE value of oil palm particleboard is low because oil palm trunks contain pith properties. Pith or central region within the OPT contains high MC which are softer compare to another part like the periphery. Therefore, when OPTB-particleboard has had pith properties, the MOE value should low. OPTB-particleboard become softer compared to one which was used other lignocellulose and non-bagasse OPT, such as wood. The variance analysis showed that the trunk's position had no significant effect on the MOE of the OPTB-particleboard. The MOE of OPTB-particleboard bonded MMA-Styrofoam in this study was lower than OPTB-particleboard bonded with PF.

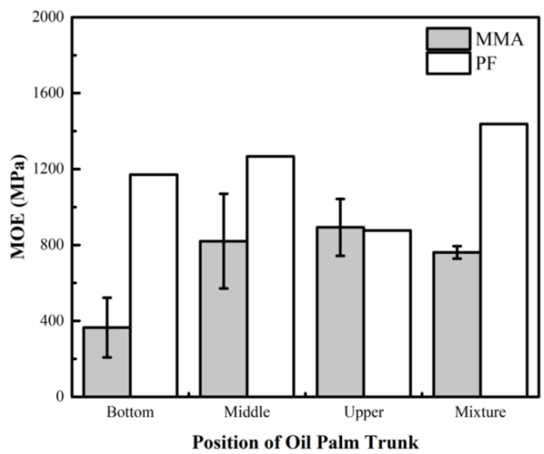

Figure 7. The MOE of OPTB-particleboard at different positions of oil palm trunk.

3.7. Modulus of rupture (MOR)

The MOR of OPTB-particleboard at different positions of oil palm trunk can be seen in Figure 8. MOR of OPTB-particleboard bonded with MMA-Styrofoam ranged from 1.78–6.69 MPa. The highest MOR was at the upper, with an average value of 6.69 MPa. Meanwhile, the lowest average value was at the bottom with an average of 1.78 MPa and was statistically significant. The MOR of OPTB-particleboard increases from the bottom to the upper and decreases in the mixed positions. Middle and upper parts were not different statistically, including the mixture. However, when using bottom part, the OPTB-particleboard was significantly different compared to the others. The MOR of the OPTB-particleboard is directly proportional to the density value. This is because the particleboard density greatly affects the strength of the particleboard [27]. The MOR of OPTB-particleboard bonded with MMA-Styrofoam does not meet the JIS A 5908-2003 standard, requiring a MOR value of 8 MPa. The size of the raw materials causes the low MOR value in the form of vascular bundles and relatively fine and short, affecting the MOR of OPTB-particleboard [28].

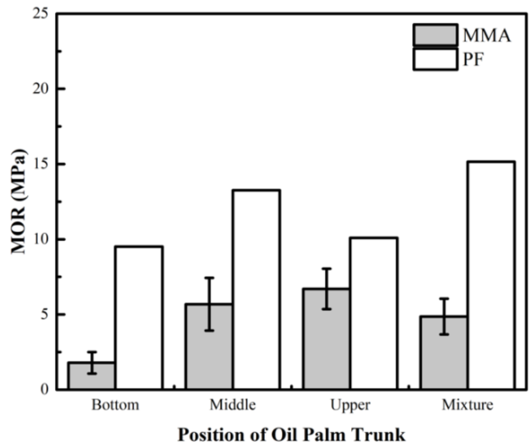

Figure 8. The MOR of OPTB-particleboard at different positions of oil palm trunk.

3.8. Internal Bonds (IB)

The IB OPTB-particleboard at different positions of the oil palm trunk is shown in Figure 9. The IB of OPTB-particleboard ranges from 0.011-0.026 MPa. The variance analysis showed that the trunk's position had no significant effect on the IB of the OPTB-particleboard. The highest IB was obtained at the bottom position with an average value of 0.26 MPa, while the smallest was obtained at the middle position with an average value of 0.011 MPa. JIS A 5908-2003 standard requires an IB value of 0.15 MPa. Based on the results, the IB of IB OPTB-particleboard does not meet JIS A 5908-2003. This is because the amount of MMA-Styrofoam binders used is still not optimal, as much as 15%. Stated [29] that a large amount of adhesive affects the value of the IB of particleboard. The optimum composition ratio between oil palm trunk and polystyrene adhesive is 60:40 [26]. However, IB OPTB-particleboard bonded with PF adhesive at the upper meets the JIS A 5908-2003 standard.

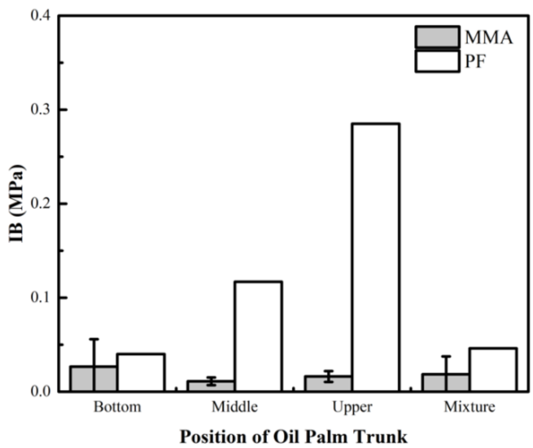

Figure 9. The IB of OPTB-particleboard at different positions of oil palm trunk

4. Conclusion

The results showed that TS, IB, MOE, and MOR OPTB-particleboard bonded with MMA-Styrofoam as a binder did not meet the standard JIS A 5908-2003. OPTB-particleboard bonded by PF have had better quality compared to those of OPTB-particleboard bonded with MMA-Styrofoam. The characteristics of OPTB derived from extraction of OPT that easily absorb water and the composition of the MMA-Styrofoam binder that is not optimal are the main factors for the low quality of the OPTB-particleboard. OPTB-particleboard bonded with MMA-Styrofoam as a binder has an optimum IB of 0.026 MPa, MOR 6.69 MPa, and MOE 892 MPa. Based on the analysis of variance, it can be concluded that there is no influence on the bottom, middle and upper except for the MOR test.

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