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The effects of metakaolin on mortar compressive strenght a case study of mortar estrich plester

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Abstract
Mortar as a binding material in couple and stucco work has long been known ranging from very simple technologies to more advanced ones. Nowadays mortar technology has developed so rapidly along with the advancement of construction technology. The development of technology in the construction industry has resulted in better product and system innovations so that they are more competitive and applicable. The demands of increasingly complex needs also need to be responded to wisely and made as hopes and opportunities in business development. Ready-mix mortar is perfect for all kinds of work such as normal masonry, light brick, stucco, ceramics, and floor coating. While from the mechanical properties, the compressive strength of the mortar can meet requirements of standard specifications according to the purpose of its use. Ready-made Dry Plaster Mortar is a mixture of fine aggregate with binding material and various additives. The purpose of using additives is to improve the properties of ready-mix plaster dry mortar. One of the additives used is metakaolin. This study aims to determine the effect of metakaolin on compressive strength and cost efficiency of plastering (mortar). The compressive pressure test object measures 50 mm x 50 mm x 50 mm. Compressive strength testing is carried out at the time when the mortar is 7, 14 and 28 days old. The study was conducted with variations in the use of Metakaolin in ostrich mortar plaster products, namely 0%, 5%, 7.5%, 10%, The results showed that a mixture of ready-made plaster dry mortar with the use of methionine 10% of the weight of cement was able to provide a ready-made dry plaster mortar that meet the requirements in ASTM C 91, Standard specification for masonry cement.

Keywords: Dry mix mortar plaster, compressive strength, metakaolin, economical and environmental benefit

Introduction
The current technological development has led to the era of globalization by emphasizing product quality and efficiency. The existence of problems that are often encountered in the field and the demands of needs must be answered by the development of innovations to produce a product that is more competitive, applicable, and easy to apply in the field. Mortar as a binding material in couple work and stucco and other finishing works plays an important role because, in addition to having to meet technical requirements, it must also provide decorative value which is high. The function of the mortar in-wall pairs is as a binder between brick elements, eliminating the deviation of the brick surface, and channeling the load received by the wall components. While the function of mortar in plastering is to level the surface, beautify the building, prevent waste of paint use and protect from the influence of the weather.

The increase in construction activities, especially buildings and housing, needs to be balanced with the availability of adequate materials. The problems faced today are the increasingly limited sources of raw materials, the difficulty of transportation, limited land, the large number of wasted materials, and the demands for product quality, especially in big cities. Therefore, it is necessary to find alternative solutions that are better in answering problems to develop technology as well as fulfill quality assurance in line with global demands.

Currently, Ready-to-Use Mortar product have been developed which are used for various jobs such as residential buildings (flats and apartments), offices, education, industry, hotels, *malls*, and others, where the demands of quality and work efficiency are indispensable. Furthermore, whether the mortar products that have currently developed are sufficient to meet the technical requirements and are for their use, needs further study and research so that can answer the problem.

This activity aims to find out the development of ready-to-use mortar products, use in the field, quality control, and recommendations for steps that need to be followed up related to standardization products that need to be compiled in the form of specifications, test methods and technical instructions on how to use them. Therefore, the study that will be carried out includes the types of ready-made mortar products, city scale, class, and building functions as well as the physical-mechanical properties of mortar. This is done to anticipate future developments that are increasingly demanding the use of mortar materials that have better, specific, cheap, and easy technical properties obtained on the market.

Based on this description and to find out whether the ready-to-use mortar products that have developed today are sufficiently qualified and by their use, it is necessary to conduct further studies so that there are no errors in use that can be detrimental to consumers. In this study, an inventory of standards, ready-to-use mortar products, usage trends, and the development of the construction industry in general in Indonesia was carried out. Some important aspects that will be identified include aspects of city scale, building location, building height, available access, transportation facilities, and arrangement/engineering traffic that is applied in a city or a certain road network. These conditions will directly affect the implementation of construction, especially in terms of material procurement, local handling or transportation, material efficiency, quality control, and the quality of the products produced.

Problem formulation

Competition in the use of ready-to-use dry mortar demands cost-saving innovations and producing the highest quality products. One way is to add material or additives to the ready-made dry mortar. One of the additive materials mentioned is the metakaolin

The fine aggregate (sand) used is silica sand. Standard mortar is a mixture that purely uses cement as a binder. So that for that can be formulated several problems as follows:

1. How does *metakaolin* affect the compressive strength of the mortar?.
2. To what extent is the percentage rate of *metakaolin* use still safe?.
3. How much is the cost-efficiency with the use of *metakaolin.*

Research objectives

This study aims to

1. Knowing the compressive strength of the mortar with cement + *metakaolin* adhesive material.
2. Knowing the percentage of *metacaoiline* which still has compressive strength according to the standard plastering strength of the walls.
3. Knowing the cost efficiency obtained when the mortar plester + *metakaolin.*

Research benefits

With mortar compressive strength that meets the standards, the mortar mix design with *metakaolin* tested can be applied to the structure of stucco and masonry work.

The results of this study are expected to be informed and disseminated so that they can be utilized and used by practitioners, the public, and the government for stucco and masonry work. For academics, it is hoped that it can grow and enrich innovations towards the maximum use of metakaolin. This is also the basis for further research on the use of methamphetamine for other ready-made dry mortars.

2. Literature Review

Mortar

Mortar is a mixture of cement, sand, and water that has different percentages. As a binding material, the mortar must have a standard viscosity. The viscosity of this standard mortar will later be useful in determining the strength of the mortar that becomes the wall plaster, so it is expected that the mortar that withstands the compressive force due to the load acting on it not be destroyed (Mulyono, 2003) [17].

Mortar and concrete are made from cement and their aggregate mixed with water. What is necessary to know from building materials are the properties of density (density), porosity, and compressive strength. Concerning heat, the mortar also needs to know its properties, for example, a wall made of concrete has a different conductivity from building materials, closely related to the use of building materials (Daryanto, 1994) [16].

The main function of mortar is to increase the attachment and resistance of ties with the constituent parts of a construction. Mortar has a relatively small depreciation value. The mortar must be resistant to water absorption and its shear strength can bear the forces acting on the mortar. If the water absorption in the mortar is too large/fast, then the mortar will harden quickly and lose its adhesion bond.

Types of mortar

Based on the type of binding material, mortar can be divided into several types. (Tjokrodimuljo 1996) [18] divides mortar into four types, namely

1. Mud Mortar
2. Lime Mortar
3. Cement mortar
4. Special Mortar

Mortar properties

Mortar can be used in certain jobs because it has several beneficial properties. Among other things, according to (Tjokrodimuljo 1996) [18], a good mortar must have the following properties:

a. Cheap.
b. Durable.
c. Easy to work with (stirred, lifted, installed and leveled).
d. Adheres well to bricks, stones, and soon.
e. Dries quickly and hardens.
f. Resistant to water seepage.
g. No cracks arise after installation.

Due to these properties, mortar has a wide scope to be applied to various kinds of work such as a binding material between one brick and another as well as to wall plasters.

Cement

Ordinary Portland cement (OPC) was used as cementing material. The strength grade of OPC was 42.5 R. The mineral and chemical compositions of OPC are shown in Table 1. The specific gravity and the specific surface area of OPC were 3.16, 3519cm/g, respectively.

Table 1: Mineral and Chemical composition of OPC

Mineral and chemical compositions of OPC.									
Mineral compositions	C_3S			C_2S		C_4AF		C_3A	
Percentage (wt%)	60.74			16.18		14.17		6.66	
Chemical compositions	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	Na_2O	K_2O	MgO	LOI
Percentage (wt%)	60.16	21.35	4.94	2.71	1.96	1.00	0.48	0.46	2.25
Note: LOI means loss of ignition.									

Source: OPC Test Analysis Results (2022) [19]

Water

Water is needed in the manufacture of mortar to trigger the chemical process of cement, wet the aggregate, and provide convenience in mortar work. Drinking water can generally be used as a concrete mixture. Water containing harmful compounds, which are polluted with salt, oil, sugar or other chemicals when used in concrete mixtures will degrade the quality of concrete, and can even change the properties of the concrete produced.

Aggregate

Aggregates are defined as granular materials e.g. sand, gravel, crushed stone, and iron furnace crusts that are used together with a binding medium to form mortar or cement concrete hydraulic or mortar. Fine aggregates are called sand, either in the form of natural sand obtained directly from rivers or excavated soils or the results of the breaking of rocks. Aggregates whose grains are smaller than 1.2mm are called fine sand, while grain smaller than 0.075 mm are called silts, and those smaller than 0.002mm are called clay.

Metakaolin

Metakaolin (MK) is a pozzolanic material. It is obtained by the calcination of kaolinitic clay at a temperature ranging between 500°C and 800°C. The raw material input in the manufacture of metakaolin ($Al_2Si_2O_7$) is kaolin Metakaolin on reaction with $Ca(OH)_2$, produces CSH gel at ambient temperature, and reacts with CH to produce alumina-containing phases, including C_4AH_{13}, C_2ASH_8, and C_3AH_6. Metakaolin had 99.9% particles b 16 µm with a mean particle size of about 3 µm (Table 2). The typical chemical composition (Ambroise *et al.*, 1994) [2] is given in Table 3.

Table 2: Metakaolin properties

Property	Value
Specific gravity	2.60
Bulk density (g/cm³)	0.3 to 0.4
Physical form	Powder
Color	Off-White
GE Brightness	79–82

Source: Ambroise *et al.*, 1994 [2]

Table 3: Metakaolin chemical composition

	% by mass
SiO_2	51.52
Al_2O_3	40.18
Fe_2O_3	1.23
CaO	2.0
MgO	0.12
K_2O	0.53
SO_3	0.0
TiO_2	2.27
Na_2O	0.08
LOI	2.01

Source: Ambroise *et al.*, 1994 [2]

Metakaolin finds usage in many aspects of concrete

- High performance, high strength and lightweight concrete.
- Precast concrete for architectural, civil, industrial and structural purposes.
- Fiber cement and ferrocement products.
- Glass fiber reinforced concrete.
- Mortars, stuccos, repair material, pool plasters.
- Increased compressive and flexural strengths.
- Reduced permeability.
- Increased resistance to chemical attack.
- Increased durability.
- Reduced effects of alkali-silica reactivity (ASR).
- Reduced shrinkage due to particle packing, making concrete denser.
- Enhanced workability and finishing of concrete.
- Reduced potential for efflorescence.
- Improved finish ability, color & appearance.

The inclusion of MK as a partial replacement of cement enhanced the compressive strength of concrete, but the optimum replacement level of OPC by MK to give maximum long-term strength enhancement was about 20% (Wild, *et al.*, 1996) [7]. Brooks and Johari (2001) [5] also reported that compressive strength increased with the increase in the metakaolin content (Table 4). Similar results were also reported by Li and Ding (2003) [9] where concrete achieved the best compressive strength with 10% MK content.

Cement pastes containing 5% to 20% MK had higher compressive strengths than the control at all ages from 3 to 90 days, with the paste containing 10% MK performing the best (Poon *et al.*, 2001) [10]. Jin and Li (2003) [13] concluded that (i) incorporation of metakaolin can prompt both the strength and modulus of elasticity development of a young concrete; and (ii) metakaolin showed the best enhancement of the mechanical properties of young concrete.

Table 4: Metakaolin effect on concrete compressive strength

Concrete mixes	Compressive strength (MPa
OPC	87.0
MK5	91.5
MK10	104.0
MK15	103.5

Source: Brooks and Johari (2001) [5]

3. Experimental procedure

This research is an experiment using ASTM C 91, the Standard specification for masonry cement, by making a test object in the form of a cube measuring 5cm x 5cm x 5cm.

The research materials used in making plaster mortar: Silica sand comes from rembang, iron sand from cilacap, the cement used is Portland cement type 1 Indonesian cement

brand, *Metakaolin* from *Antec* and water PDAM Lab Bahan Bangunan UGM.

Testing of physical properties and the manufacture of Mortar test objects measuring 5cm x 5cm x 5cm was carried out at the Estrich Mortar Laboratory and compressive strength testing was carried out at the Building Materials Laboratory of Gajah Mada University.

Before making a mortar test object, the materials consisting of silica sand and iron and are tested for their properties first, which are tested consisting of volume weight, sludge content, substances organic, water absorption, moisture content, and sand gradation.

Mixing Proportion

After all the materials are ready for the mixing process, then cement, silica sand and iron sand and *metakaolin* are mixed until evenly distributed well based on the predetermined composition of the mixture. The material that has been mixed evenly is added with water and stirred until a mixture that is ready to be printed is obtained into the cube mold that has been prepared before.

Sample preparation

After the material mixing process is carried out, the concrete mixture is put into a 5cm x 5cm x 5cm cube mold which has previously been smeared with oil or lubricating oil on the inside of the mold which aims to make it easier when removing the test object from the mold after it hardens. The mixture is put into the mold with standard pressure and compacted by piercing the mixture in the mold.

Test methods

Ready and hardened test objects Treatment Test ObjectsThe test material is ready and has hardened damage or defects, then immersed in water until it reaches the life required for robust testing.

The data taken in this study are aggregate property data and mortar compressive strength at maintenance ages of 7 and 28 days. Then a comparison will be made with the value of the normal mortar compressive strength. This is done to obtain data on the increase or decrease in compressive strength caused by the use of quicks and instead of sand and an increase in compressive strength due to the influence of the addition of *fly ash* as a partial replacement of cement. After the test object undergoes a treatment or *curing* process, namely treatment by immersion on the entire surface of the mortar for the desired life, then a compressive strength test is carried out to know the compressive strength value of the mortar based on the difference in its maintenance life. The test sequence includes the following:

a. Test objects are tested at the age of 7 days, 14, 28 days.
b. Test objects weighed in weight.
c. The test object is placed on the compressive strength machine.
d. The machine is started and by using a data logger, the maximum compressive strength data of the test object is recorded.

Mechanical properties

The compressive strength test under ASTM C 349 Standard test method compressive off hydraulic cement mortar, the strength can be calculated by the following formula:

$$Sc = F / A$$

Where

Sc is compressive strength, MPa,

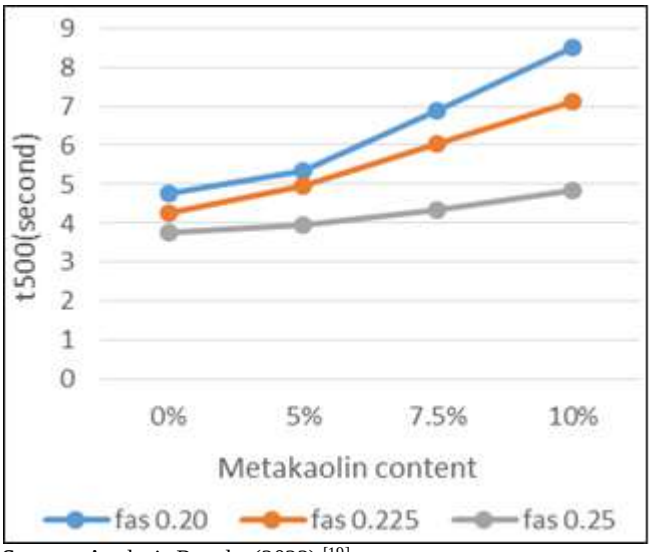
F is failure load of specimen, N

A is section area of the specimen, mm2

4. Result and discussion

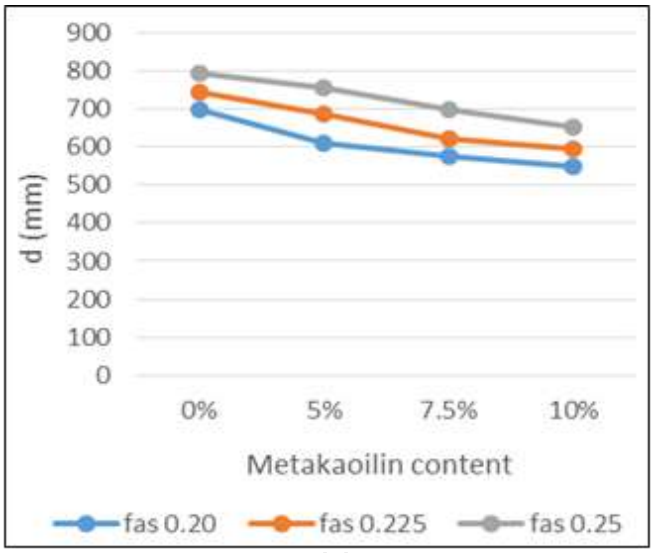
4.1 Fresh Properties

The slump of fresh mortar with different Metakaolin contents is shown in Fig 1. T 500 slump test fresh mortar with various MC and Fig 2. Slump test fresh mortar with various MC.



Source: Analysis Results (2022) [19]

Fig 1: T 500 slump test fresh mortar with various MC



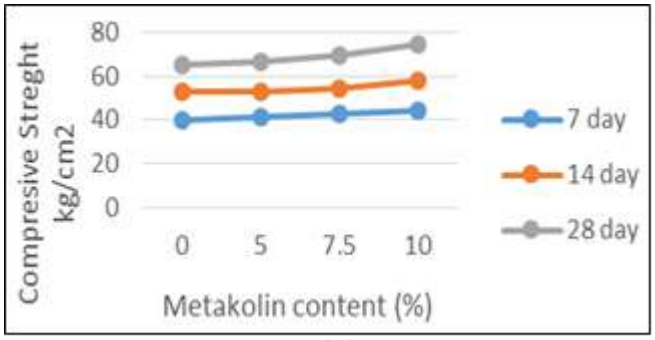
Source: Analysis Results (2022) [19]

Fig 2: Slump test fresh mortar with various MC

Figure 1 and figure 2 show that the addition of metakaolin decreased the ability of fresh mortar to flow because the viscosity of the mixture increased with the increase in the amount of metakaolin as a cement substitute. The three variations of FAS used gave the same results for each variation of metakaolin where higher FAS values gave the mortar ability to flow better.

4.2 Mechanical properties

The compressive strength of mortar with different metakaolin powder contents is shown in fig 3.



Source: Analysis Results (2022) [19]

Fig 3: Compression test result with various MC at, 7day, 14 day and 28 day

The experiment result as seen in figure 3 shows that the result of compression increases at 9,44 kg/cm2 or 14% of compressing strength by adding 10% metakaolin.

4.3. Analysis of economic and environmental benefits.

In this paper, Metakaolin powder replaced part of the cement. From economic and environmental protection, the advantages of using metakaolin as cementing material include: decreasing the dosage of cement and so reducing the mining of limestone. Saving energy in the calcination proses because the calcination temperature of metakaolin was 900 C, which is lower than 50-300^{o}C limestone. These benefits reduce the economic and environmental costs.

5. Conclusion

To optimize the use of metakaolin in wall plaster dry mortar, mechanical properties are studied. The conclusions are as follows:

1. The slump of fresh mortar that the addition of metakaolin decreased the ability of fresh mortar to flow because the viscosity of the mixture increased with the increase in the amount of metakaolin as a cement substitute.
2. The compressive strength of mortar increase with metakaolin addition, rapidly, with 14, 5% with the addition of 10% off metakaolin powder.
3. Considering the economic and environmental benefit of mortars with the different metakaolin powders, we can use less OPC and replace it with metakaolin powder to have the same compressive strength.

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