Potential of activated carbon in lime mortar plastering in term of fire resistance and thermal performance

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Abstract. The use of lime mortar plastering for wall construction in residential and light commercial buildings has increased significantly over the world. The unique characteristic of hydrated lime increases the strength of the tensile bond. The more considerable the amount of cement content in cement lime mortar, the low the air content; thus, the bond strength stronger. The performance of plastering under fire exposure is an item of significant importance in securing construction. Activated carbon is one known adsorbent which has a high capacity to adsorb gases and improved fire resistance ability of concrete. The purpose of conducting this study is to identify the optimum proportion of lime mortar plastering containing activated carbon with different percentages which is 0%, 10%, 30% and 50% as cement replacement. Therefore, a fire resistance test was conducted on cement plaster mixtures with variable ratio content of activated carbon to identify the optimum proportion according to the temperature reading by an infrared thermometer for 30 minutes. Based on the results obtained, the sample with 30% activated carbon as cement substitution was the most effective since it gave a relatively low initial temperature reading which was 28.2ºC. The test showed only a slight increase in temperature after the first five minutes, which is 93.1% and reached 108.2ºC at maximum even after 30 minutes of testing. There was no hair crack developed, and no visible of smoke observed from the sample compared to existing plaster which formed hair crack and visible of smoke at 280ºC after 16 minutes of testing. Therefore, 30% of activated carbon is the optimum proportion in lime mortar plastering due to ability to resist fire and prevention from hair crack and visible smoke formation. This proportion can be applied to the interior and exterior wall of the building, especially at the compartment wall and along the escape route.

1. Introduction

Fire is one amongst the natural hazards that attack the buildings. No building material is entirely fireproof [1]. However, fire can be controlled by a fire protection system or early fire detectors. According to the Fire Services Act (Act 341) and the Uniform Building by Law, UBBL (1984) are relevant (i.e. Malaysia). (1984), fire detectors are necessary for the building and should be placed in each building space. Designing structures against fire attack is continuously attracting more importance and investment on a global scale. Uncontrolled fires can cause huge number of injuries, fatalities and economic loss [2].

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Generally, there are four ways that fire can spread via heat transfer. These are through convection, conduction, radiation, and direct burning. Convection is defined as the transmission of heat within a liquid or gas and is due to their difference in density. While conduction is the transmission of heat through materials when there is sufficient heat present, it may be enough to ignite fuel through other objects. Besides, that fire spread by radiation can occur by waves travelling until other objects absorb heat and the simplest way to spread the fire is by direct burning. The more objects the fire gets in contact with, the more significant probability that the fire will be able to spread faster.

One part of the fire design is fire resistance. Fire resistance is defined as the duration during which a structural member exhibits resistance concerning structural integrity, stability, and temperature transmission under fire conditions [3]. Generally, fire resistance of a structural membrane depends on the materials used in construction. The use of non-combustible materials, less smoke emitting materials should have a fire rating of minimum from two hours to maximum of four hours [4]. Previous studies show that at Saravana store commercial building in Tamil Nadu, the reason for live losses is dumping of combustible materials, heavy fire, thick smoke and no possibility of escaping from the building. Plaster is a layer of plaster on an interior or exterior wall structure [5].

Plaster has been used in passive fire protection as fireproofing products because it has a major role in the prevention of fire spread. Activated carbon is one of the material that can improve the fire resistance of concrete [6]. Therefore, in this study, the main objective is to find the optimum proportion of activated carbon in lime mortar plastering by conducting a fire resistance test on different percentage of activated carbon. Within this fire resistance plaster, it is expected that residents, users and building visitors will survive in the presence of fire in the building because it will slow down the spread of fire.

2. Background

Fire could be extremely dangerous if there is no equipment or protection system to control the early detection or the spread of the fire. Therefore one of the most essential systems in the building is fire safety and protection system. Understanding the concept and characteristic of fire is very helpful to design a well-performed fire protection system.

One of the simplest ways to understand the basic of fire is the fire triangle and fire stage. Both of this will help the firemen and the occupants to extinguish the fire. But to extinguish the fire, the fire protection system will be used. Fire protection of buildings, the preventive and protective measures that will protect persons in the event of a fire, fall into two broad categories referred to as passive and active protection [7].

Passive fire protection (PFP) is about a system which is designed to prevent, contain or slow the spread of fire of origin to other areas in the building. It also can be defined as a system that retards the speed of fire and smoke spreading as protection of escape routes in order to prolong the escape time by designing and modifying architectural elements with fire resistance characteristic. For example, building structure, escape route, stairs and fire doors. Stairways must be at least 6 meters for width as to make sure firefighters can easily keep occupants safely [8].

While active fire protection system is an approach or a process of protecting a building or structure from fire by using the methods of applying automatic or manually operated fire mechanical system in a building to provide safety to the users in a building. One standard function that all the system shared in an active fire protection system is to slow down the process of burning in a building, putting out the fire and to notify the fire and smoke condition. This active system includes fire alarm, heat detector, smoke detector and sprinkler.

2.1. Fire stage

International Fire Service Training Association (IFSTA) is relevant (i.e. Malaysia) states that there are four levels of fire stages. These stages are incipient, growth fully developed and decay [9]. For a fire to occur, the three elements must be combined in the right proportions, which are oxygen, heat and fuel. If any of the three elements is removed, the fire will extinguish. The firing stage shows that the fire begins with incipient. Then, it is developed into a growth phase, where the heat release rate increase until the fire is fully developed. The flame temperature may be well above at 540°C [10]. In a
compartment fire, the transition from the growth stage to the fully developed stage may involve a flashover. Flashover is a transition in the development of a contained fire [11]. Typically occurs when the upper gas layer reaches 600°C.

Once combustion begins, development of an incipient fire is mainly dependent on the characteristics and configuration of the fuel. The present of the air provides oxygen to continue the development of fire. During this initial phase of fire development, radiant heat warms adjacent fuel and continues the process of pyrolysis [12].

The growth stage is where the structures fire load and oxygen are used as fuel for the fire. Numerous factors that are affecting the growth stage, including where the fire started, what combustibles are near it, ceiling height and the potential for thermal layering.

Fully developed is the sudden transition from a growth stage to developed set fire fully. At this stage, a rapid transition occurs to a state of total surface involvement of all combustible material within the compartment [12]. When fully developed stage ended, the decay stage begins. If the fire continues to smoulder, the compartment will fill with dense smoke and gases and temperatures could reach well over 1000°C [10]. At this stage, the fire will begin to decrease due to the reduction in oxygen levels in a space which will then make the fire to extinguish itself.

2.2. Fire resistance

International Fire Service Training Association (IFSTA) is relevant (i.e. Malaysia) states that there are four levels of fire stages. These stages are incipient, growth fully developed and decay [9]. For Example The fire safety measures for structural members are measured in terms of fire resistance. Fire resistance is defined as the duration during which a structural member exhibits resistance for structural integrity, stability, and temperature transmission under fire conditions. The fire resistance of a structural member is dependent on the geometry, the materials used in construction, the load intensity, and the characteristics of the fire exposure itself [3].

In practice, if the volume of the building is high, the load intensity should be also high. If it is in a controllable limit, it is suitable for the building. Still, if it exceeds the controllable limit, it will create property losses in life where the direct consumption of combustible materials by fire flame, heat and smoke. Besides, the materials used in the construction must have adequate resistance to overcome flames and the spreading of fires.

2.3. Lime mortar plastering

The fire safety measures for structural members are measured in terms of fire resistance. Fire resistance is defined as the duration during which a structural member exhibits resistance concerning structural integrity, stability, and temperature transmission Lime plaster and mortar were first described in the literature by Vitruvius in Rome 2000 years ago. Lime is produced in a process called the lime cycle; burning, slaking, carbonation. The parameters of each step in this cycle can affect the properties of the final material in several ways [13]. Lime is produced from limestone containing mainly calcite CaCO3. This chemical composition also affects the slaking procedure and hardening.

According to Kreuger (1920), three kinds of the binder are used in lime-based mortar which is lime, hydraulic lime and cement. The production of this binder includes burning limestone with or without clay minerals at a temperature of 900-1500°C. The amount of cement content in mortar significantly increases its mechanical strength. As cement content increases, more water is necessary to achieve advisable consistency where the content of the air in mortar decreases [14].

When a mortar is chosen for a specific building, it should always be adjusted to the surrounding materials and the construction of the wall. The mortar should attach well and at the same time, be possible to remove. Before applying a mortar to a wall, the wall must be cleaned from humus and dust. Otherwise, the mortar will not attach well.

2.4. Activated carbon

Indicate the e-mail address of the author to whom any correspondence should be addressed on a new line directly after the author affiliations. The fire safety measures for structural members are measured in terms of fire resistance. Fire resistance is defined as the duration during which a structural Coconuts
have been an integral part of the diet in the tropical climate where the choice of coconut shell over other waste raw materials is due to its availability all year round. Low cost, its lack of alternative use, and its possession of advantageous properties such as high carbon content and high mechanical strength [15]. The traditional term for activated carbon is activated charcoal. Activated carbon as produced from thermal cracking of biomass has a high specific surface and a porous structure with noticeable fluid which is gas and liquid as absorbing properties. Addition of activated carbon to high-performance concrete in optimal dosages does not affect its performance, both in the fresh and hardened state [5]. Activated carbons are complex products which are difficult to classify based on their behavior, surface characteristics and preparation methods. However, classification is made for general purpose based on their physical characteristics which are powdered and granular [16-17].

A previous study had conducted a fire test on concrete to study the mechanisms of the spalling of concrete when it is exposed to fire. The results obtained in the present research which show a minimal spalling depth of the concrete. Because concrete is the most widely used material on the planet and because activated carbon is inert in respect of atmospheric oxygen, incorporation of 1% of this material in concrete could perceivably lower the carbon footprint of concrete, leading to a market of tradable carbon credits on the order of tens of billions of dollars in the next decades [18].

3. Experimental Programme

The following study on methodology includes the information of the experimental procedures. This study explained, described and discussed the processed of research and instruments that had been used during data collection and methodology to analyses and to obtain the result to achieve the objective of the study.

3.1. Sample forming

The traditional term for activated carbon is activated charcoal [19]. The sample is formed according to the different percentage of activated carbon in lime mortar plastering, which is 0%, 10%, 30% and 50%. Table 1 below shows the samples according to the ratio.

| Sample | Ratio of AC (%) | Initial Temperature | 5 Mins | 10 Mins | 15 Mins | 20 Mins | 25 Mins | 30 Mins |
|--------|----------------|---------------------|--------|---------|---------|---------|---------|---------|
|        |                | (°C)                | (°C)   | (°C)    | (°C)    | (°C)    | (°C)    | (°C)    |
| 1      | 0              | 30.4                | 268.4  | 279.6   | 309.6   | 329.8   | 341.4   | 354.2   |
| 2      | 10             | 29.4                | 118.1  | 174.9   | 170.9   | 184.1   | 181.5   | 185.1   |
| 3      | 30             | 28.2                | 93.1   | 88.9    | 98.3    | 126.7   | 115.1   | 108.2   |
| 4      | 50             | 28.4                | 106.8  | 117.6   | 127.4   | 118.5   | 116.7   | 113.0   |

3.2. Sample testing

Fire resistance test is done by applying a direct flame to all the samples for 30 minutes. For every 5 minutes, the temperature is recorded by using an infrared thermometer. The temperature is taken around 2 to 3 cm from a direct flame to the sample. This infrared thermometer laser can read until 420°C only.

4. Result and discussion

4.1. Sample 1

The data was obtained through a straw bale fire test in the Furniture Fabrication Laboratory, Universiti Tun Hussein Onn Malaysia (UTHM). The parameter assessment in this study is temperature. The data in table 1 of fire temperature is obtained by recording the surface temperature of the samples by using a laser thermometer. Sample 1 known as a standard plaster which has 0% of activated carbon. It has
the highest cement content, which is 0.51kg. Figure 1 below shows a graph of temperature against time for sample 1.

![A graph of Temperature against Time for Sample 1](image)

**Figure 1** A graph of Temperature against Time for Sample 1

Figure 1 describes the graph where the temperature is increasing linearly with the time. After 16 minutes, it developed a hair crack at the highest surface above the exposed area with 1.80cm size. The crack length increased in size by the time, and smoke was visible during 280°C. At the end of the test, the crack length was increased until 1.93cm. The initial temperature for the sample 1 was 33°C and final was at 354.2°C as recorded by a thermometer laser. This is the highest initial temperature compared to the other samples. The temperature increased gradually during the total lifetime of the testing, where the total increase is 323.8°C.

4.2. *Sample 2*

Sample 2 has 10% amount of activated carbon as a replacement of cement, and the percentage of cement is 90%. Straw balefire test was done in 30 minutes, and every 5 minutes, the temperature was recorded using an infrared thermometer. The temperature was taken around 2cm to 3cm from the area which it is directly exposed to the direct flame. Figure 2 below shows a graph of temperature against time.

![A graph of Temperature against Time for Sample 2](image)

**Figure 2.** A graph of Temperature against Time for Sample 2

Sample 2 with 90% of cement content which is 0.462kg and 10% of activated carbon which is 0.051kg describes the graph where the temperature is increasing slowly with the time. During 30 minutes of the testing, there was no hair crack developed and smoke visible. Compared to sample 1, the hair crack started to develop, and the visible of smoke was at 280°C. For sample 2, the maximum temperature it can reach is at 185.1°C. For the first 5 minutes, the temperature reached at 118.1°C only compared to sample 1, which is 268.4°C. This can be said that sample 1 undergoes combustion faster compared to sample 2 because there was no activated carbon mixed in sample 1. The amount of
activated carbon undergoes adsorption of oxygen slowly due to 10% of activated carbon in this sample.

The initial temperature for sample 2 before testing was 29.4°C and final was at 185.1°C as recorded by the thermometer laser. The temperature increased slowly and slightly decreased after 10 and 20 minutes which are from 174.9°C to 170.9°C and from 184.1°C to 181.5°C. The difference between temperatures was 88.7°C for the first 5 minutes, where it was the highest difference between the other temperatures. It can be said that the combustion started to occur as in a stage of fire, during ignition, the combustion occurs very quickly, and the temperature was increased dramatically [9].

4.3. Sample 3
Sample 3, which have 30% amount of activated carbon as a replacement of cement and the percentage of cement is 70%. Straw balefire test was done in 30 minutes, and every 5 minutes, the temperature was recorded using an infrared thermometer. The temperature was taken around 2cm to 3cm from the area which it is directly exposed to the direct flame. Figure 3 below shows a graph of Temperature against Time.

![Graph of Temperature against Time for Sample 3](image)

**Figure 3.** A graph of Temperature against Time for Sample 3

Sample 3 with 70% of cement content which was 0.359kg and 30% of activated carbon which was 0.154kg describes the graph where the temperature is increasing slowly with the time compared to sample 1, and its temperature is rising drastically. During 30 minutes of the testing, there was no hair crack developed and smoke visible. Compared to sample 1, the hair crack started to develop, and the visible of smoke was at 280°C.

For sample 3, the maximum temperature it can reach was only at 108.2°C, and this is the lowest final temperature compared to all four samples. By referring to figure 3, the temperature reached for the first 5 minutes is 93.1°C only compared to sample 1, which is 268.4. This can be said that sample 3 undergoes adsorption higher compared to sample 1 and 2 due to the optimum proportion of the activated carbon and the amount of cement content in the sample. As cement content increases, more water is necessary to achieve advisable consistency where the content of the air in mortar decreases [13].

The initial temperature for sample 3 before testing was 28.2°C and final was at 108.2°C as recorded by the infrared thermometer. During 0 minutes to 5 minutes, the difference between temperatures was only 64.9°C, where it was the highest differences between the other temperatures. The combustion started to occur as in a stage of fire, during ignition, the combustion occurs very quickly, and temperature was increased dramatically compared to the other stage. From the analysis, it can be concluded that sample 3 has the optimum proportion of the activated carbon since the temperature of the sample is in stable compared to other samples and fire resistant in the form of activated carbon has high gas adsorption capacity [20].
4.4. Sample 4
Sample 4, which have 50% amount of activated carbon as a replacement of cement and the percentage of cement is also 50%. Straw balefire test was done in 30 minutes, and every 5 minutes, the temperature was recorded using an infrared thermometer. The temperature was taken around 2cm to 3cm from the area which it is directly exposed to the direct flame. Figure 4 below shows fire testing for sample 4.

![Figure 4. A graph of Temperature against Time for Sample 4](image)

Sample 4 with 50% of cement content which was 0.257kg and 50% of activated carbon which was also 0.257kg describes the graph where the temperature is increasing and decreasing slowly with the time compared to sample 1 where its temperature is increasing drastically. During 30 minutes of the testing, there was also no hair crack developed and smoke visible, which has the same pattern for sample 2 and 3. Compared to sample 1, the hair crack started to develop, and the visible of smoke at 280°C and sample 1 have no amount of activated carbon.

For sample 4, the maximum temperature it can reach was only at 113.0°C, and this is the second-lowest final temperature compared to all four samples. The temperature reached for the first 5 minutes is 106.8°C compared to sample 1 which is 268.4°C. But, for sample 3, which its temperature for the first 5 minutes is 93.1°C. This can be said that sample 4 undergoes lower adsorption, and due to the amount of cement content in the sample which is 50%, the air content in this sample is higher than sample 3.

The initial temperature for sample 4 before testing was 28.4°C and final was at 113.0°C as recorded by the thermometer laser. During 0 minutes to 5 minutes, the difference between temperatures was 78.4°C, where it was the highest difference between the temperatures. Therefore, it can be concluded that the combustion started to occur as in a stage of fire, during ignition, the combustion occurs very quickly and the temperature was increased dramatically compared to the other stage.

4.5. Comparison between all the samples
From the graph in figure 5, sample 1 shows the temperature is increasing drastically from the first 5 minutes until 30 minutes. The initial temperature for sample 1 is the highest temperature which is 33°C compared to other samples. Sample 1 has 0% of activated carbon which is the standard ratio for lime mortar plastering. It undergoes combustion quickly compared to other samples where its temperature for the first 5 minutes reached until 268.4°C while the other samples is not exceeding than 120°C. The temperature for sample 1 is kept increasing until it reached 354.2°C after 30 minutes. Besides, sample 1 developed a hair crack, and smoke started to visible for 16 minutes at 280°C. The hair crack increased from 1.80cm until 1.93cm at the end of the testing.

For sample 2, the temperature is increasing with time but slowly than sample 1. Sample 2 has only 10% of activated carbon where activated carbon helps to slow down the process of combustion and decrease the reading of temperature compared to sample 1. But it has the highest final temperature, which is 185.1°C compared to sample 3 and 4. Similar to sample 2, the graph of sample 4 also is
increasing slowly but during 15 minutes, it started to decrease from 127.4°C to 113.0 at the end of the testing. This sample has 50% of activated carbon, where it has the highest percentage of activated carbon compared to other samples.

Sample 3 with 30% of activated carbon has the lowest initial temperature among the other samples, which is 28.2°C. From the graph, it shows that temperature is in stable because it is slightly increased and decrease with the time. The maximum temperature it can reach is 126.7°C at 20 minutes and started to decline slowly until 108.2°C at the end of the testing. This shows that activated carbon is at optimum proportion since it can control the temperature in a stable state.

The initial temperature for sample 4 before testing was 28.4°C and final was at 113.0°C as recorded by the thermometer laser. During 0 minutes to 5 minutes, the difference between temperatures was 78.4°C where it was the highest difference between the temperatures. This can be concluded that the combustion started to occur as in a stage of fire, during ignition, the combustion occurs very quickly and temperature was increased dramatically compared to the other stage.

![Figure 5.4 A graph of comparison between all samples](image)

5. Conclusion
The experiment was conducted on lime mortar plastering with different percentage of activated carbon which is 0%, 10%, 30% and 50%. All objectives are achieved. Data collection on temperature and observation were then analyzed. The result was compared to the temperature and the percentage of activated carbon during the fire resistance test. The pattern of lime mortar plastering was observed if there was any smoke visible or hair crack developed during 30 minutes of testing. From the observation, 30% of activated carbon contained in lime mortar plastering as a replacement of cement is the optimum proportion for plastering. From the analysis, activated carbon could improve fire-resistant and undergoes adsorption of gases, thus slow down the process of combustion. Besides that, there was no smoke visible or any hair crack developed compared to the existing plaster which contains 0% of activated carbon.

The development of fire stages also supports Malaysia Fire and Rescue Department (also known as BOMBA) to identify and control the fire. It is believed that by conducting this study, it will help the researchers to design and carry out a research project related to fire-resistant plaster to upgrade fire preventing system technology, save human lives and property. The protection for plaster is important since it is the outer layer of the wall inside and outside of the building, regarding its function, where it has the significant role in the prevention of fire spread. This lime mortar plastering that contains the optimum percentage of activated carbon can be applied to the interior and exterior of the building.

6. References

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