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RESEARCH ON THE REDUCTION OF CARBON EMISSIONS IN BUILDINGS BY SPECIFYING LOW-CARBON CONCRETE MIXES IN CHINA

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A B S T R A C T

Buildings are key contributors to the emissions of toxic carbon dioxide, which is a global greenhouse gas, and lowering the concentration of this gas is an essential mitigation in mitigating the effects of climate change. This study majorly focused on the strategies that could be applied in the building and construction industry to help in lowering carbon concrete in concrete mixes. Various challenges were reported to be prevailing when it comes to the adoption of the use of low-carbon concrete in the construction sector. The cost of low-carbon concrete alternatives was among the topmost challenges that made most of the owners of the construction projects apply them. The study was conducted at Huajie Construction Company, which was among the leading construction companies in China. This facilitated the acquisition of accurate information as per the needs of the research objectives. For data collection, 150 participants were selected from this company through the implementation of a purposive sampling technique. Therefore, to address all these, some low-carbon concrete alternatives were suggested for adoption in construction activities. These alternatives included: carbon capture concrete, hempcrete, ferrock, recycled aggregate concrete, and geopolymer concrete. All these alternatives had safe properties that could help to lower carbon emissions.

1. INTRODUCTION

Buildings as well as construction activities were considered as being among the top-most contributors of carbon emissions, accounting for almost 35% of environmental carbon content globally (Onat & Kucukvar, 2020). These emissions were primarily a result of energy consumption in building and construction activities, and also during household activities. Due to this, reducing carbon emissions in buildings was essential mitigation for addressing climate change and achieving a more sustainable future (Fawzy et al., 2020). From the extraction and use of carbon-based building materials to the energy required for heating rooms constructed of carbon-based materials, both the construction and operation of buildings have a significant impact on the environment (Huang et al., 2018). The United Nations Environmental

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Program (UNEP) report made it abundantly evident that, in the absence of effective mitigations to reduce the environmental carbon content, the building sector's carbon footprint might treble by 2050.

Several approaches could be implemented to reduce carbon emissions in buildings, for example, the application of sustainable building design and construction practices, as well as reducing excessive heat emission in rooms (Hertwich et al., 2019). Successful application of these measures needed a combination of technical solutions, policy interventions, and behavioral changes. One of the most efficient methods for lowering carbon emissions was suggested to be improving energy efficiency in rooms. To help with this, a variety of methods could be used, such as increasing building insulation and installing energy-efficient equipment (Li et al., 2017). Additionally, using renewable energy sources like solar could significantly reduce the amount of carbon dioxide emitted from buildings.

Using sustainable building design and construction methods was crucial for reducing carbon emissions. This included the application of construction materials with no or low carbon content, incorporating green spaces to promote biodiversity, and designing buildings with passive solar features to lower energy consumption in such buildings. Furthermore, reducing carbon emissions that were associated with the construction process could be achieved through various strategies, for example, through the use of carbon concrete and minimizing waste (Ahmed et al., 2020). All these could have a positive impact on lowering the carbon footprint. Effective policy interventions were also essential to incentivize and promote the adoption of health and safety measures that could help to reduce the use of high-carbon concrete in the construction process (Ye et al., 2017). Moreover, the government could also offer financial incentives for the implementation of safe building codes and standards that could improve the energy performance of buildings constructed from carbon-based concrete. Public education and campaigns could also be introduced and successfully implemented to help in reducing carbon emissions in buildings and divert the behaviors of the buildings' occupants. Reducing carbon emissions in buildings was an essential strategy for mitigating the environmental and health impacts of climate change (Cordero et al., 2020). This research aimed at exploring the most effective approaches for reducing carbon emissions in construction activities and introducing policies that are appropriate for their adoption. This research enabled us to develop effective mechanisms for lowering the carbon footprints of the building industry and improving sustainability efforts.

2. PROBLEM STATEMENT

The intensive emission of carbon by households, industries, and construction sites in China has been increasing in the past five years. In 2021, the Chinese government, through environmental health and environmental health professionals released a report that highlighted several construction sites and manufacturing industries as being the leading emitters of carbon dioxide, an environmental pollutant, and a pulmonary toxicant. The report was much more detailed and it stated that the buildings in China together with the construction industries are generally accounting for over 10% of China's carbon emissions (Chi et al., 2021). In this study, the researchers found that the manipulation of different building materials, including cement and steel, which are highly concentrated with carbon after their production process, is one of the major causes of carbon emission in both buildings and construction sites. The report also emphasized the necessity of reducing the usage of these carbon-based materials and promoting the adoption of low-carbon substitutes in order to reach the carbon reduction targets established by the Chinese environmental experts. Additionally, the researchers in their report discussed the advantages of sustainable structural design and safe construction techniques, as well as the necessity of implementing higher energy efficiency in both commercial and residential buildings. The key technique for achieving all of these goals was to address carbon emissions in buildings. The Chinese government had set a goal of reaching peak carbon emissions by 2030 as well as a neutral level of carbon emissions by 2060.

3. RESEARCH OBJECTIVES AND METHODOLOGY

3.1 Research Objectives

1. To identify potential carbon emissions linked to the production and use of concrete mixes
2. To evaluate the environmental and health impacts of carbon emissions from concrete mixes.
3. To identify the properties of low-carbon concrete mixes that make them better alternatives.
4. To analyze the economic strengths of using low-carbon concrete
5. To identify barriers and opportunities for the introduction of low-carbon concrete mixes

3.2 Methodology

3.2.1 Study Variables

The independent variables for this study were; construction techniques and government policies. The dependent variables on the other hand included: indoor air quality and energy consumption.

3.2.2 Study Participants

The study was conducted at Huajie Construction Industry, which was located in China. The study participants were recruited through the implementation of a purposive sampling technique since only the respondents, who had adequate knowledge of the techniques for reducing carbon emissions were needed for the study. The study participants for this research included: building owners, structural designers, government agencies, engineers and contractors, and building occupants. Building owners were involved in the study to check whether they may be convinced to adopt new construction materials that had no low carbon content, as well as sustainable building practices. Structural designers, on the other hand, were involved in the study since they were having essential knowledge in constructing energy-efficient buildings, thus lowering the chances of carbon emissions. Moreover, engineers were very essential for this study since they were the ones involved in the implementation of sustainable construction technologies and systems in buildings. It was the system that could also help to reduce the rates of carbon emission during construction activities. Government agencies were considered essential since they had an interest in developing and enacting health and safety policies and regulations that could help to incentivize or require buildings to reduce carbon emissions. Furthermore, the building occupants had a great positive impact on carbon emissions since their household practices, habits, and behaviors could reduce the levels of energy consumption, thus lowering the probability of high temperatures in rooms, a condition that had been identified as one of the most dominant in carbon emissions.

4. DATA COLLECTION

4.1 Questionnaires

The questionnaires that had relevant questions for the study were applied in this research. These questionnaires exposed various objectives that were related to carbon emissions. In this study, 5-point Likert scale questions were applied to help in recording relevant information from the study participants. The questionnaires were uploaded to the website that was being used for data collection, while some were printed. Therefore, the respondents could access questionnaires through offline or online techniques. Questionnaires were primarily chosen for this study because they are accessible, simple to assess, and can be dispersed widely. Additionally, using questionnaires to poll a large number of respondents was time and money efficient

4.2 Interviews

In this research, one-on-one interviews were also conducted at Huajie Construction Company to help in supplementing the information that could not be captured in the questionnaires. The basic reason for applying interviews in data collection was because it promoted an immediate and direct collection of data from the study participants. It was applied to research participants, who could not be physically located in person. The participants were reached using phone and video calls, and the interviewees' comments were recorded for later study.

5. DATA ANALYSIS

5.1 Carbon Emission

Causal relationships help predict a future event, change the future via public policies and individual actions, and reflect and elucidate why such events occurred. Finding the causes, instead of the relationships, aims to help make better decisions. Furthermore, the contemporary study is grounded on determining the relationship between the factors such as success criteria and success factors concerning the reduction of carbon dioxide emission, making causal research design the ideal. The fig.1 shows Beijing's carbon emissions for the period 2012-2021. From the fig.1, we can know that Beijing's carbon emissions fluctuate considerably.

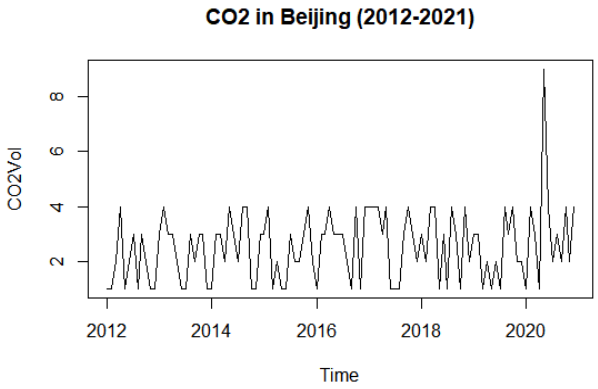

Figure 1. CO_2 emissions in Beijing from 2011 to 2021

Figure 2 shows the fuel use in Beijing in different seasons. Season changes for the period show a higher fluctuation due to a trend change in Beijing. This is due to changes in fuel consumption, leading to increased carbon emissions. It is not easy to reach out to the whole populace to obtain a relevant sample from the data. Nevertheless, it is hard to identify a sufficient sample that can be regarded as a true representation of all the oil and gas industries in China. Therefore, a sample population of 50 managers in the oil and gas industry in Beijing will be used for this study. This sample is adequate to get branched-out opinions and perspectives about the issues and variables for the present study.

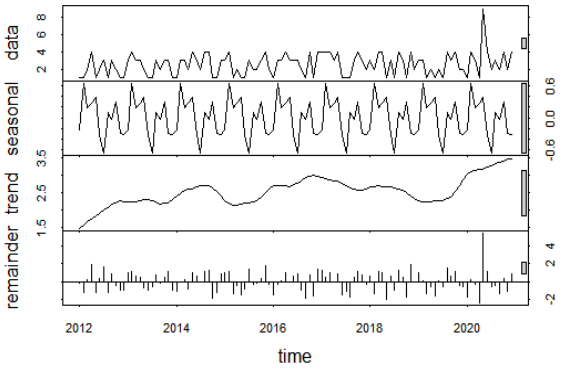

Figure 2. Fuel use in Beijing during different seasons

To get and reach out to the target populace, a sample selection method has to be identified, and the most suitable one is convenience sampling. A convenience sample can be regarded as a non-probability sampling method whereby a sample is obtained from a group of people that can easily be reached. It is also referred to as availability sampling or grab sampling method. Data used in this study is from the climate of Beijing, which shows the rate of emissions in China for the period between 2012-2021 (fig. 3-6).

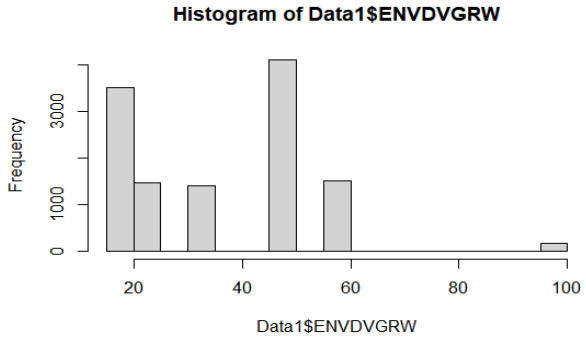

Figure 3. Histogram of Data1$ENVDVGRW

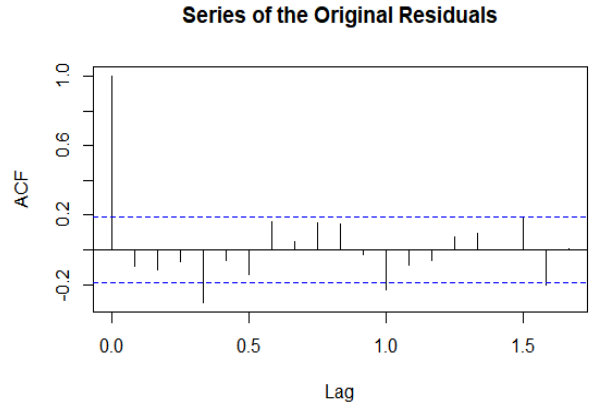

Figure 4. Series of the Original Residuals

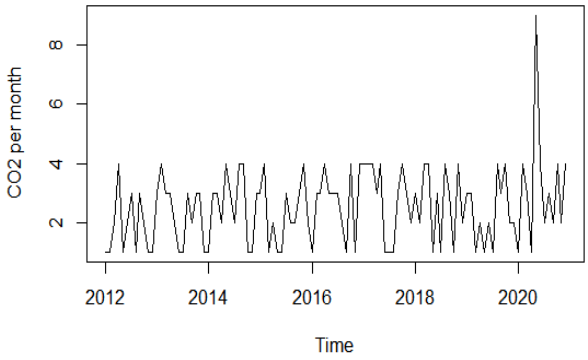

Figure 5. Wage Flactuation

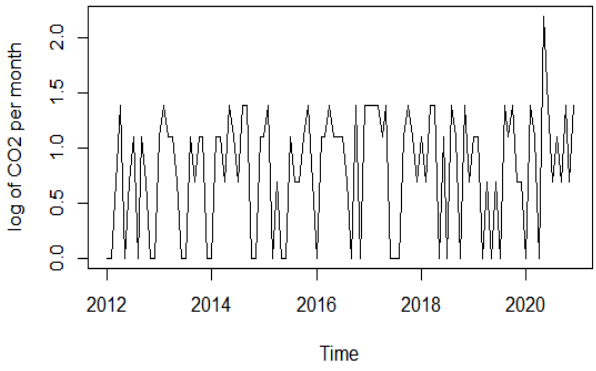

Figure 6. Log of CO_2 in Beijing

To sum it up, if China comes anywhere close to realizing its goals in climate change, then the oil and gas industry will have to play its part. Undoubtedly, the increase in natural gas consumption has contributed to increased production and, in turn, a high carbon dioxide emission rate. Even though the emittance of this gas has posed a serious threat to the environment, it can also be an opportunity for the industry to convert it into something useful, such as methanol. This may be the game-changer considering oil and gas production is important to the Chinese economy.

6. RESULTS AND DISCUSSION

6.1 Potential carbon emissions linked to the production and use of concrete mixes

In this research, various sources of carbon emissions that were prevailing in the Huajie Construction industry were highlighted by the interviewees. According to Figure 7, the most common sources of emissions that were identified included: embodied carbon (36.41%); energy use (32.53%); transportation activities (13.59%); waste disposal (12.41%), and building demolition (5.06%).

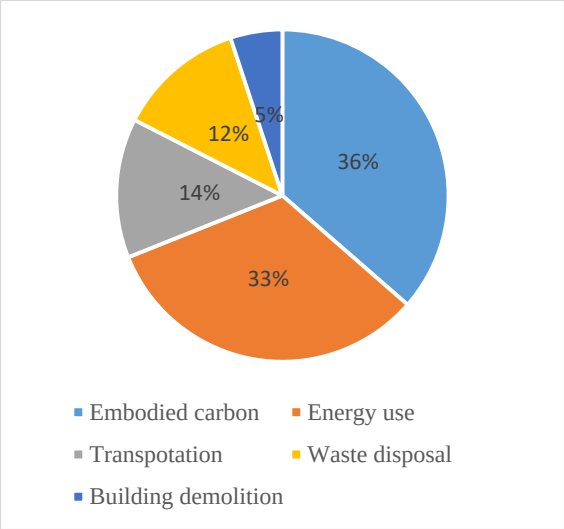

Figure 7. Sources of Carbon Emissions in the Huajie Construction Industry

The manufacturing, shipping, and installation of carbon-based concrete mixtures, such as steel and concrete, were identified as the construction industry's most significant source of carbon emissions. This is due to the fact that carbon was the most prevalent component in the manufacturing of the majority of these materials (Huang et al., 2018).. Moreover, energy use in the construction industry was also reported to as a source of carbon emissions, an incident that had a great negative impact on both the surrounding environment and the exposed employees. Most of the construction machines that were manipulated in this construction, for example, excavators, trenching machines, graders, land rollers, and concrete mixers were using carbon-based fuels such as petroleum as their source of energy for operation. Therefore, during the operation of these machines, the chemical combustion of petroleum triggered the release of carbon dioxide gas as a waste product (Wu et al., 2019). This gas was being released directly into the atmosphere, thus leading to several ecological changes. Furthermore, unsafe operations by employees, especially failure to put on appropriate PPEs could also result in the development of pulmonary disorders such as bronchitis.

The industry was also characterized by intensive transportation activities, ranging from the distribution of materials to the transportation of waste products to disposal points. All the transport vessels that were being used in these activities used petroleum as their source of energy for operations (Hu et al., 2019). Similar to how operating machinery involved chemical reactions, using these vehicles involved burning petroleum, a process that also led to the production of hazardous chemicals like carbon dioxide and carbon monoxide into the atmosphere.

Waste management, which was another aspect of the building sector, was thought to be a significant source of carbon emissions with detrimental effects on the environment. Poor waste management resulted in issues with both environmental and human health. This industry ranged among the topmost industries as far as the emission of carbon was concerned (Wang et al., 2019). In most cases, when wastes from construction industries were disposed of, they majorly accumulated in landfills. When trash have accumulated to a certain point, landfills begin to degrade and emit methane, one of the most poisonous gases and a greenhouse gas that causes climate change in the area around landfills. This is due to the fact that methane had a capability to capture heat from the atmosphere that was nearly 20 times greater than that of carbon dioxide. Moreover, waste disposal in the construction industry also resulted in carbon emissions through transport activities. When the construction wastes were being transported to the landfills, the designated disposal points, the vehicles doing the transportation consumed carbon-based fuels as the source of energy. Burning of these fuels during vehicle operations released carbon dioxide into the environment, contributing to increased carbon emissions.

Furthermore, the construction industry was also identified to be having waste materials such as wood, plastics, and metals that the industry could either recycle or reuse for other activities. However, it was discovered that the environmentalist in the industry was not keen on separating and recycling the wastes to get back those that can be reused. As a result, it was necessary to develop new materials, which necessitated the consumption of energy to run industrial machinery. The increased release of carbon-based gases like carbon dioxide and monoxide was the principal effect of this.

Like other activities that were leading to increased carbon emissions in the construction industry, building demolition was also identified to be having a high capacity for releasing carbon. This activity majorly involves both the dismantling and deconstruction of a building. To begin with, building demolition resulted in increased carbon emissions through the release of greenhouse gases that are produced by the deconstruction of building materials (Ma et al., 2023). Most buildings contained various construction materials including concrete, brick, and steel that had their greater portion occupied by carbon. When a building was demolished, these materials released their carbon component into the atmosphere, and this results in increased carbon emissions. Similarly, heavy machinery such as excavators and graders that were used in the demolition process also used carbon-based fuels, which released carbon during their combustion.

6.2 Environmental and Health Impacts of Carbon Emissions

The research aimed at construction workers from the Huajie Construction industry in China. This

construction industry was preferred because of the willingness of its members to offer accurate and quality information to the researchers. Moreover, most of the construction activities of this industry are conducted in strategic locations that can be easily accessed by the researchers for data collection. About the potential effects that carbon emissions from concrete mixes could have on both human health and the environment, 150 construction employees were questioned throughout the process. Figure 8 shows that 40.22 percent of the interviewees strongly agreed that carbon emissions had an effect on both human health and the ecosystem, whereas 19.31 percent agreed and 7.42 percent did not express an opinion. Furthermore, 27.82% strongly disagreed with the proposal, and 5.23% disagreed.
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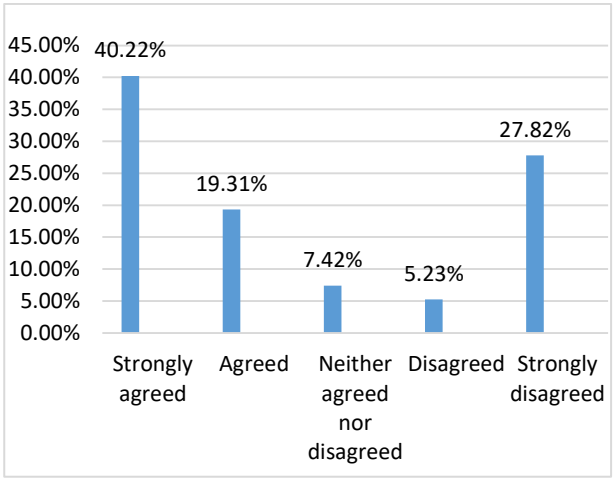

Figure 8. Interview on the environmental and health impacts of carbon emissions

From those who agreed, several impacts of carbon emissions on both the ecosystem and human health were stated. To begin with, excessive emission of carbon beyond the safe recommended level is a major cause of climate change in the surrounding environments. The main causes of respiratory issues like hypoxia are elevated quantities of carbon-based gases in the environment, such as carbon dioxide and carbon monoxide produced by concrete mixtures. Since carbon dioxide is a gas that dissolves in water, its high atmospheric concentration can also raise the acidity of nearby water bodies including lakes, rivers, and streams (Jiang et al., 2022). This is due to the fact that during rain, the gas dissolves in the water to create weak carbonic acid, which is then directly released into the water bodies. Increased concentrations of acid in the water bodies had a great negative impact on the aquatic ecosystem, including both plant and animal species.

Furthermore, it was suggested that carbon emissions from the concrete mixes in the construction industries also had a great negative impact on the availability of water. Climate change, which is a major result of increased carbon emission caused significant changes in the environmental precipitation patterns thereby leading to reduced rainfall. Due to this, water scarcity was experienced in most of the areas surrounding the construction industries. Reduced or no rainfall that resulted from increased levels of carbon emissions also caused a problem with soil degradation (Lu et al., 2022). This is because it triggered changes in weather patterns, which caused both soil erosion and nutrient depletion, all of which had an impact on lowering the agricultural productivity of the surrounding land.

From the human health perspective, those who agreed reported that various human health problems had been developed by some casualties, including the construction workers following exposure to the carbon-based gases that are emitted from the concrete mixes (Figure 9). The most common problems were respiratory problems such as bronchitis and asthma that most workers developed in their career practice. All these were triggered by prolonged exposure to toxic carbon-based gases such as carbon dioxide. Bronchitis was an inflammatory respiratory disorder that majorly occurred in the bronchial tubules of most employees. This condition was reported by 32% of the construction workers, who had been exposed to carbon emissions for over five years (Dong et al., 2021). The inflammation of these tubules was characterized by excessive production of mucus, an incident that triggered difficulty in breathing among the casualties. Other than carbon dioxide gas, the employees also reported various forms of carbon emissions such as dust, soot, and smoke that were also associated with concrete mixes were also reported to be accounting for the incidence and prevalence of respiratory disorders among them. The accumulation of these materials in the lower parts of the lungs also triggered inflammatory responses that caused difficulty in breathing.

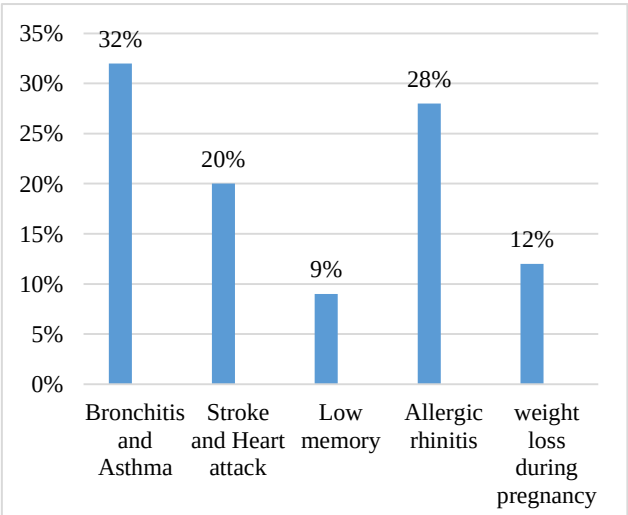

Figure 9. Interview on the Potential Health Impacts of Carbon Emissions among Employees

Similarly, some neurological problems were also reported at this construction site. Most workers were found to be taking too long to think about simple concepts that could be solved in a very short duration. This incident was noticed in almost 9% of the construction workers, who were found at the site. The main logic behind this is that exposure to carbon-based gases resulted in cognitive decline, which is characterized by both memory loss and reduced attention span of the casualties (Jacobson et al., 2019). Furthermore, some female construction workers, who are operating in this industry also reported some reproductive health problems that they have experienced during their pregnancy period. 12% of these female workers reported that continuous exposure to carbon emissions during the pregnancy period made them experience low birth weight, fetal development disorders (both anatomical and physiological) as well as increased risk of preterm birth. Various allergic reactions were also reported by hypersensitive construction workers, who were operating without PPEs in an environment full of carbon emissions. A number of them developed respiratory allergic reactions such as allergic rhinitis, which was characterized by frequent sneezing. This was reported by about 28% of the exposed construction workers. Likewise, 22% of the workers also reported suffering from conjunctivitis, an allergic reaction that occurs on the white part of the human eye (conjunctiva). This form of allergic reaction is associated with symptoms such as aching eyes and prolonged release of tears.

Moreover, cardiovascular problems such as stroke and heart attacks were also reported by some of the workers, who had experienced prolonged exposure to the toxic carbon emissions. Stroke and heart attack were reported as being the most stressful chronic cardiovascular disorders that were experienced by almost 20% of the interviewed employees. These workers were exposed to carbon-based particulate that used the respiratory tract as the portal of entry into the body and caused damage to the cardiovascular system. Exposure to these toxic materials was reported to induce both inflammation and oxidative stress in the hearts and blood vessels of the exposed workers. The inflammatory responses then triggered increased levels of plaque in the employee's arteries, an incident that led to increased chances of developing stroke (Azuma et al., 2018). Moreover, oxidative stress was also reported to be damaging the cells and tissues in the cardiovascular system. Following all of these was the rise in blood pressure, which was brought on by the narrowing of the arteries, which served as the main conduits for the transit of blood throughout the cardiovascular system. Blood clots were reported to be developed as a result of high blood pressure, which also had a significant part in the constriction of the blood vessels. The impairment of vascular function, or the blood vessels' physiological capacity to dilate and constrict in response to variations in blood flow, was then brought on by elevated blood pressure. This decreased the amount of blood going to the neural system, especially the brain.. Low or no blood supply to the brain triggered the occurrence of stroke among the employees, who had been exposed to carbon particulates.

6.3 Properties of low-carbon concrete mixes that make them better alternatives

From this research, five types of low-carbon concrete mixes were proposed for construction works to help in reducing the rates of carbon emissions into the surrounding environment. These alternatives were; geopolymer concrete, carbon capture concrete, recycles aggregate concrete, hempcrete, and ferrock. To begin with, geopolymer concrete was made from a mixture of various industrial by-products such as slag. This type of low-carbon concrete was found to be having a lower carbon footprint and also stronger than normal concrete since it didn't need high temperatures during its processing. This resulted in reducing the emission of greenhouse gases such as carbon dioxide that had highly affected the environment. Moreover, geopolymer was found to be having high durability due to its compressive strength that surpasses the strength of traditional cement (Almutairi et al., 2021). These properties made some respondents propose it as a better alternative for a variety of construction activities such as the construction of residential, road construction, and construction of commercial rooms. Geopolymer also had high chemical resistance, which made it a better alternative to use in environments where buildings were exposed to toxic chemicals that could increase the rate of structural degradation. Such environments include chemical processing plants and industrial facilities.

Moreover, fire resistance was also highlighted as another significant property of this alternative low-carbon concrete. This was due to the high melting point of the materials used in the production of geopolymer concrete. Because of this, the majority of responders recommended this as a very good substitute for concrete when building fire-proof structures such fire-resistant walls and fire barriers. This could lessen the possibility of a fire spreading and the amount of carbon dioxide gas that might be produced as a carbon emission in the event of a fire incidence.. Furthermore, geopolymer concrete was also a recyclable alternative that could be used in future construction activities (Amran et al., 2020). This could help to reduce the chances of carbon emissions through waste disposal if in any case a building had been demolished. The improved insulation property of this concrete also convinced a number of the research respondents to consider it as a better option for construction activities. The superior insulation property of the materials in the concrete helped to reduce energy consumption in buildings, a factor that also reduced the release of carbon dioxide. All these properties and benefits made this concrete material to be considered to

be effective in lowering carbon emissions by 16% of the respondents (fig. 10).

The second alternative that was also proposed as being appropriate for construction to help in reducing carbon emissions was carbon capture concrete. The research discovered that the option was having a perfect strategy for reducing the concentration of carbon dioxide in the atmosphere. Carbon capture concrete absorbed carbon dioxide gas from industries and incorporated them into a concrete mix. The carbon dioxide gas chemically reacted with the calcium ions, the most dominant component of cement to form calcium carbonate, which had some safe properties that made it a better option for construction activities. To begin with, it reduced carbon footprint since it incorporates carbon emissions from the atmosphere thus helping to reduce the chances of climate change. Moreover, this alternative also had high durability potential as compared to traditional concrete mixes. This was majorly a result of good compressive strength that surpasses that of traditional concrete. Application of this concrete in construction activities such as the construction of residential apartments and road construction could help to reduce the chances of these structures demolishing and releasing toxic carbon-based materials into the atmosphere.

The materials applied in the production of carbon capture concrete were found to be having high chemical resistance, a property that made the concrete to be suitable for use in building chemical production industries (Peng et al., 2023). This could help to reduce the probability of carbon being released from chemical reactions between highly concentrated chemicals and concrete on either the wall or the floor. Fire resistance as a property of carbon capture resistance also helped to reduce the chances of concrete undergoing combustion and releasing carbon emissions such as carbon dioxide and carbon monoxide gases. In addition, carbon capture concrete was also recyclable and thus could be used in other construction activities following the demolition of a structure. This property also helped to reduce the rate of production of such concrete, thus helping to lower the amount of carbon dioxide that was being released into the atmosphere during the operation of machines used in the production process. Of the 150 respondents interviewed during the research, 25% of them supported the use of carbon capture concrete.

Another significant low-carbon alternative that was suggested from this research was hempcrete, a bio-based construction material that is generated from the woody core of the hemp plant. This alternative also possessed a variety of properties that made it a better substitute for traditional concrete. This alternative was supported by 22% of the interviewed research respondents. To begin with, this alternative was found to be sustainable since it is made from a renewable resource that consumes very little energy during its production. Hempcrete was also found to be biodegradable and thus could not accumulate in the environment to form big landfills (Demir & Dogan, 2020). Moreover, hempcrete as a substitute for traditional concrete had good insulation properties, thus could help to reduce energy costs by keeping the rooms warm for a long period, especially during cold winter seasons. It could also help to control humidity levels within the room, thereby improving the quality of indoor air. In addition to these, hempcrete also had good thermal mass, a property that made it to store heat and release it in bits especially when the need arises in the rooms. This property also reduced the chances of hempcrete undergoing combustion during high temperatures or fire outbreaks. Since the concrete was made from inorganic materials, it was found to be fire-resistant thus lowering its chances of burning and also increasing its reliability. Hempcrete also had a low carbon footprint thus it required a low amount of energy for its production as compared to other traditional alternatives of concrete. Following the fact that most of the industries that were producing these concrete materials used carbon-based fuels such as petroleum and diesel as their machines, therefore reduced energy consumption during the production of hempcrete lowered the amount of petroleum used and the volume of carbon dioxide released following the combustion of petroleum. This also acted as a strategy for reducing carbon emissions.

From this research, ferrock was also discovered as a better alternative that could help to reduce the amount of carbon emissions during construction works or demolition. Ferrock was found to be a bio-based building material that was produced from industrial waste products such as steel dust and silica. The respondents explained that during the production process of this construction material, steel and silica were mixed with both water and carbon dioxide gas to help increase both the durability and the sustainability of the material. This concrete material was characterized by several properties that made it a better option to substitute traditional concrete, thus making it to be supported by 20% of the respondents. To begin with, the material was sustainable as it was made from waste products that could otherwise be disposed of in landfills to cause environmental pollution. Moreover, the material was also discovered to be fire-resistant, a property that made it not to burn and release toxic fumes and gases in case of a fire incident (Niveditha et al., 2020). Ferrock also had a low carbon footprint since its production consumes carbon dioxide. This greatly helped to reduce the emission of greenhouse gases such as carbon dioxide. Furthermore, the good thermal property of the concrete material also made it a suitable alternative to traditional concrete. This property enabled it to regulate the temperature of the room and also lowered its chances of cracking in case of a temperature change.

Another low-carbon option that was suggested for use in place of conventional concrete was recycled aggregate concrete. 20% of the survey participants, who were curious about the quality of this concrete material, held this opinion. According to research conducted by Wang et al. (2021), this sort of concrete is made from a range of recycled resources, including recycled glass, crushed brick, and crushed concrete. Various properties of this low-carbon concrete alternative made it suitable to be used in the construction of commercial rooms, residential apartments, learning facilities, and road construction. The first property was their reduced impact on the environment. The production of this concrete manipulated waste products from various industries that helped to reduce cases of environmental pollution. Secondly, this concrete also had high durability and high compressive strength that could surpass that of traditional concrete. In addition, recycle aggregate concrete also reduced its carbon footprint since it lowered the need for virgin materials as well as the amount of waste generated during construction activities. Production of recycled aggregate concrete from recycled waste products made it to have increased thermal insulation as compared to traditional concrete that was associated with high carbon concentration (Xiao & Xiao, 2018). This property made the material to be considered as being ideal for constructing buildings and rooms that might be associated with high-temperature operations such as cooking. In addition, most of the materials that were used in the production of recycled aggregate concrete had good sound absorption, thus making the concrete also have an increased level of sound absorption. The property made the respondents support this alternative.

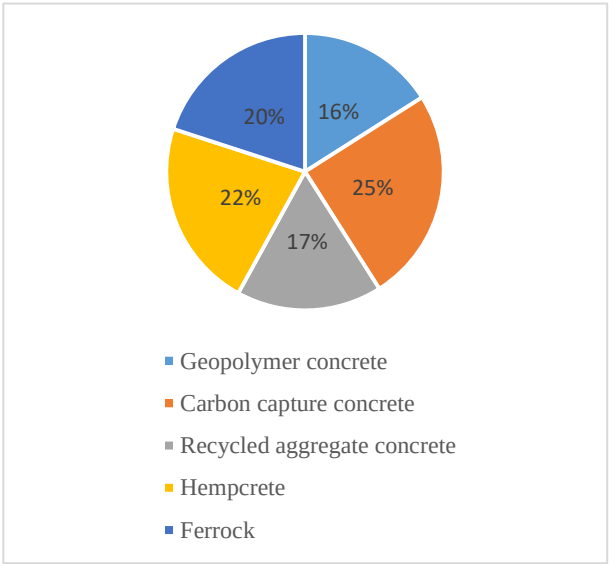

Figure 10. Respondent's preference for the low-carbon concrete mixes alternative

6.4 Economic strengths of using low-carbon concrete

From this research, many economic strengths had been discovered to be attached to the low-carbon concrete in the construction industry. One of the common economic strengths of using low-carbon concrete is cost-saving over the long term. Even though most building and construction enterprises were found to be selling these materials at higher prices, however, it was proved that their use can reduce the overall cost over the life of a building. The main reason behind this was the density and the strength of these materials. This reduces the potential of almost all buildings made of these materials breaking down, and causing a need for repairs and replacements (Al-Noaimat et al., 2022). Furthermore, through this research it was discovered that a greater percentage of buildings that had been made of low-carbon concrete had an improved quality of air indoors, thus reducing expenses on installing a ventilation system for the building.

Similarly, the use of low-carbon emissions was the potential for market differentiation and increased demand. Due to the increased spread of the concept of sustainability in most building designs and construction, many buildings that were made with low-carbon concrete were highly preferred by entrepreneurs and tenants for commercial and residential purposes, respectively. In addition, since these buildings were of good quality, there was another strength of increased rental rates and overall returns for the building owners. Furthermore, the use of low-carbon concrete had helped to reduce the regulatory risks that are associated with the use of traditional concrete (Sanytsky et al., 2020). This is because a greater percentage of governments globally as well as international environmental organizations had set and implemented policies that were aimed at reducing the atmospheric concentration of carbon and carbon-based gases. As a result, using low-carbon concrete is a wonderful way to comply with regulatory requirements and lessen the risk of paying fines or facing other consequences for breaking these rules.

Additionally, the usage of low-carbon concrete provided excellent business opportunities for those looking to enter the production of these environmentally acceptable materials. Since there was a larger market for these resources because of the rising demand, there has been more investment and growth in the regions where these commodities are produced.. The use of these construction materials was also confirmed to be having an impact on improving the public image of an apartment. This is because most tenants could consider the construction industries that had set up such apartments as being both environmentally responsible and socially conscious (Lehne & Preston, 2018). Another economic strength of using low-carbon concrete in building and construction was the potential for carbon offset revenue. This is because most of the construction industries and enterprises that were engaged in both selling and using low-carbon concrete

were able to sell carbon offsets as well as participate in carbon markets, thereby generating an additional revenue stream for their investment. Moreover, ease of access to green financing was also another potential economic strength attached to the use of low-carbon concrete in the construction industry. Most owners of apartments, which were constructed using low-carbon concrete were eligible for green financing that offered very low interest rates and other financial benefits.

7. CONCLUSION

In conclusion, this research explored some of the most effective low-carbon alternatives that could help to reduce carbon emissions in buildings, and also some of the policies that could be developed to help in the adoption of these safe alternatives. Public education and public campaigns were some of the mechanisms that could be applied to enlighten building owners, construction managers, and construction engineers on the safety associated with the use of low-carbon concrete alternatives such as hempcrete and ferrock. Successful adoption of these alternatives could be a perfect avenue for China to reach its set visions by 2060.

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