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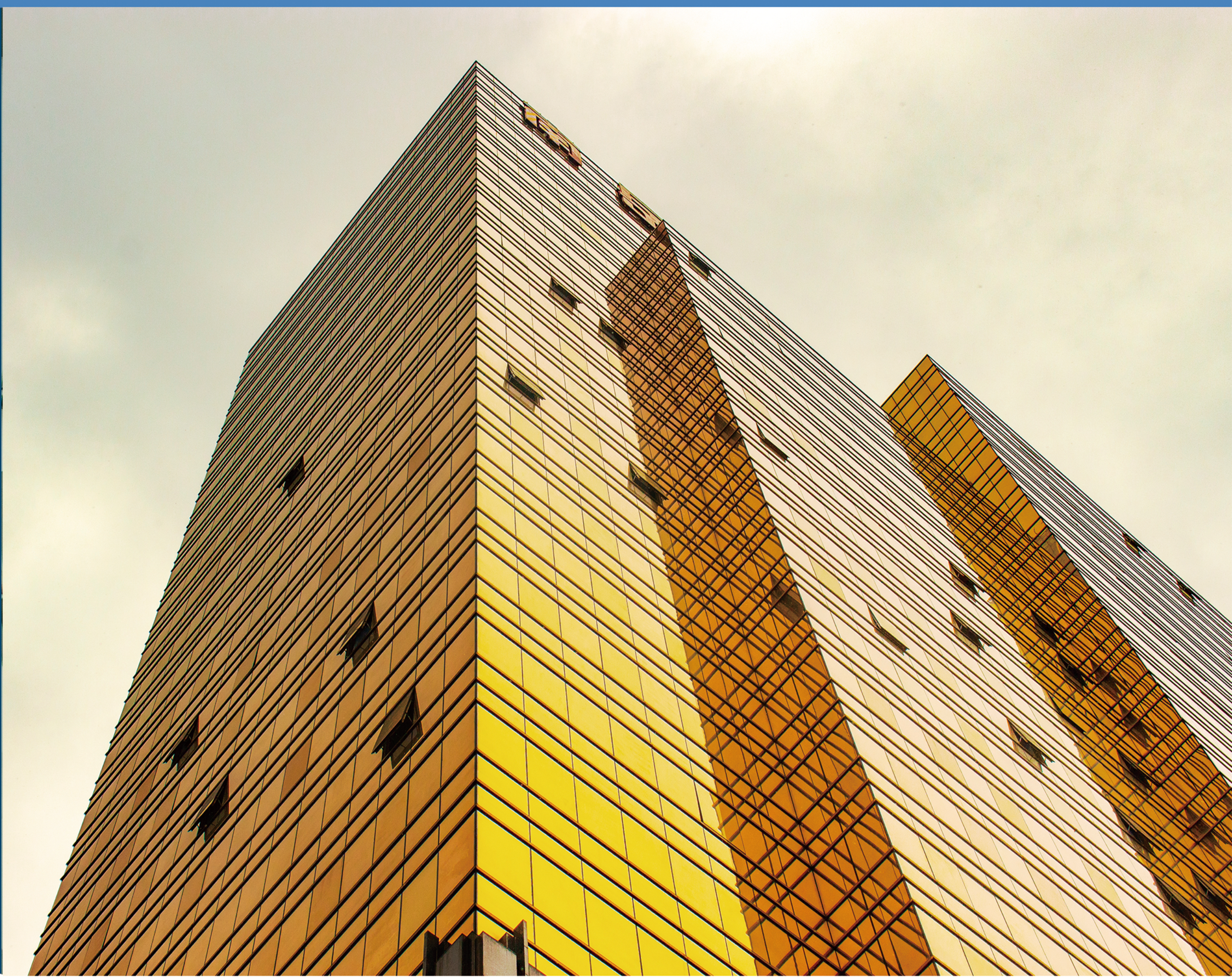
JOURNAL OF
BUILDING MATERIAL SCIENCE

Volume 2 | Issue 1 | June 2020 | ISSN: 2630-5216 (Online)



Volume 2 Issue 1 • June 2020 • ISSN 2630-5216 (Online)

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BILINGUAL PUBLISHING CO.

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ARTICLE

The Importance of Occupational Health and Safety (OHS) and OHS Budgeting in terms of Social Sustainability in the Construction Sector

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ARTICLE INFO

Article history
Received: 12 November 2020
Accepted: 10 December 2020
Published Online: 31 January 2021

Keywords:
Social sustainability
Construction Sector
Occupational Health and Safety

ABSTRACT

Nowadays, sustainability is one of the most important construction sector goals, as it is in most other sectors. However, sustainability in the construction sector is dealt mostly with its environmental and economic dimensions, and its social dimension remains in the background. This situation causes the Occupational Health and Safety (OHS), which is perhaps the most important issue within the scope of social sustainability, to be addressed on its own, and its relationship with sustainability to be not introduced clearly. This study discussed the relationship between social sustainability and OHS in the construction sector. Based on the fact that in construction projects, the sustainability goal should be revealed forward to a great extent at the design stage, how to contribute to OHS by budgeting OHS activities together with project activities was explained. We intended to contribute to the provision of OHS and thus the social sustainability of construction projects by revealing how the budgeting will be done and how much OHS budget will be, by referring to the studies in the literature conducted about OHS budgeting and presented robust numerical data. The study is expected to help construction sector stakeholders to understand the relationship between social sustainability and OHS and to provide a clear picture of the role of budgeting in this respect.

1. Introduction

Even though sustainability was used to address the environment as of its first appearance and aimed to sustain the environment in a quality way, nowadays, it has become a concept that is accepted to have three pillars: environmental protection, economic development, and social improvement. It has been understood that it is impossible to protect the environment without providing economic development and creating a socially equitable system. Similarly, sustaining the economy without a habitable environment and a good social environment is so difficult, and neither the environment nor the economy has any meaning without social sustainability, whose focus is people.

On the other hand, overall sustainability is an issue that can be achieved with the contribution of all sectors related to production. Sustainability is extremely important in the construction sector since this sector consumes

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lots of resources in the construction, use, and demolition stages of the buildings, the economy is extremely important at every stage of the sector, and the social life is shaped around the buildings created by this sector. However, as in most other sectors, in the construction sector, sustainability's economic and environmental dimensions are emphasized, and social sustainability remains in the background. This situation causes neglect of many social aspects of construction projects.

This situation causes OHS, which is actually one of the most critical parts of social sustainability in construction projects, not to be dealt with together sustainability and handled completely independently. However, it is clear how weak the environmental, economic or social sustainability claim will be in a sector in which per year 2.3 million and per day 6000 employees die due to 340 million occupational accidents and 160 million occupational diseases.

One of the most important reasons for the failure of providing OHS in the construction sector is that the OHS expenditures, which are not included in the design and tender stages, are seen as an extra cost during the construction phase and tried to be avoided. In fact, the budgeting of OHS costs during the design phase will be extremely beneficial in terms of the contractor's prediction and implementation of OHS activities and the employers requesting the contractor's full implementation. This study was carried out from this point of view. The social sustainability-OHS relationship in the construction sector and the importance of OHS budgeting in this relationship were revealed. Studies in the literature, which were carried out about OHS budgeting and presented the amount of budget needed for OHS with numerical data, were examined. In this way, in a construction project, how OHS budgeting will be done and how much budget is needed were revealed. Thus, we aimed to contribute to the stakeholders' understanding of the relationship between social sustainability, OHS, and OHS budgeting in construction projects and their taking action in this direction.

2. Social Sustainability and OHS in the Construction Sector

2.1 Sustainability

Ruckelshaus defined sustainability as the doctrine of providing economic growth and development with mutual interaction within the broadest boundaries of ecology and protecting it within time [1]. According to World Health Organization, sustainable development is the strategy to meet the demands of the current world population without causing an unfavorable impact on the environment and health, and without draining or imperiling the worldwide resource base, thus without trading off the capacity of people in the future to meet their demands. Accordingly, human beings are at the focal point of worry for sustainable development. They are entitled to a healthy and productive life in amicability with nature. Although previously sustainable development was generally used to address the environment and was pointed out to the environment's sustaining quality [2], nowadays, sustainable development is acknowledged to have three fundamental dimensions: environmental protection, economic development, and social development. The United Nations 2005 World Summit result report referred to them as "interdependent and mutually reinforcing pillars." These dimensions are generally known as sustainability pillars and triple bottom line (TBL). TBL comprises of three Ps: Profit, People, and Planet. It intends to quantify the organization's environmental, financial, and social performance over some time [3]. Essentially, sustainability is associated with resources, which include human, natural, and financial resources. HR may contain the laborers, customers, investors, and all partners who impact the organization and would be affected by its business. This way, sustainable development focuses on preserving and keeping up such resources as productive as possible to utilize the present and future generations [4].

To sum things up, the critical concern of sustainable development is individuals and their life quality. Correspondingly, sustainable development regards the economy absolutely as the key for the human and his fulfillment in life. Also, it considers the environment since the quality of everyone's life is impacted essentially by the environment, nature, and resources. It considers society since the level of satisfaction of individuals is important. Hence, the social dimension got less acceptance within the context of sustainable development [5].

2.2 Social Sustainability and Construction Sector

Social sustainability, which covers traditional social policy areas and principles, and subjects like participation, social capital, economy, environment and quality of life, interests on how people, communities, and societies live together and how they act by taking into account the physical boundaries of the space they are to achieve their chosen goals [6]. With its most general definition, "It is ensuring the efficient use of natural resources by present and future generations by the protection and development of social conditions which will support meeting human needs and ensuring environmental sustainability."

  DOI: https://doi.org/10.30564/jbms.v2i1.2591

Socially sustainable development is the development that enables society to work as a whole by helping each other to achieve common goals. At the same time, it can meet individuals' daily needs, such as health, housing, nutrition, and cultural expression [7-9].

The sustainability goal in the construction sector should include environmental and economic goals as well as social goals. However, this is not the case in practice. According to Valdes-Vasquez, while environmental and economic sustainability increases focus on CE programs, social sustainability gets little consideration in the classroom. To better understand the situation, it would be well first to understand what social sustainability means for the construction sector [10].

Valdes-Vasquez and Leidy defined social sustainability as a series of processes that develop wellbeing, health and safety and think about the need for both present and future partners [11]. According to them, incorporating these perspectives and regarding the whole project life cycle may give an increasingly comprehensive grasp of this concept for the construction industry than a distinct definition allows. As indicated by Almahmoud and Doloi, with regards to construction, the social sustainability concept is represented by meeting and managing different stakeholders from different sectors like industry, clients, and neighborhood communities [12].

From the perspective of construction firms, social sustainability focuses likewise around the usage of corporate obligation practices [13], which consider how the organization can address the demands of partners impacted by its operations [14]. For instance, at the design stage, the designers, government offices and construction firms attempt to provide worker safety by wiping out potential security risks from the site of work [15-16].

Miree and Toryalay stated that considering safety design and security design is critical in the design phase since health and safety issues concerning project stakeholders were a general worry in construction projects in terms of social sustainability [17]. Besides, in construction, it is required to increase a project's safety and health performance. It is agreed that health and safety is a significant prerequisite, which has to be provided for workers and the surrounding community. The construction workers ought to be given proficient information and vital protection to have the option to work under safe conditions [12]. In general, sustainability literature recommends that healthy and safe working and living conditions are critical parts of social sustainability along with the project's impact on the local society through its life cycle [18].

2.3 Occupational Health and Safety (OHS)

Definitions regarding the relationship between social sustainability and the construction sector reveal that the focus of the issue is OHS. The contemporary meaning of the concept of OHS, apart from the diagnosis and treatment of occupational accidents and occupational diseases, is to protect the health of the employee and eliminate the various dangers that may disrupt his / her health [19]. OHS is an all-encompassing methodology which intends complete prosperity of the employee at work. As per WHO, subjects like security, physiotherapy, work-related medication and psychology, ergonomics, rehabilitation, and so on are associated with occupational health. On the other hand, safety is protecting the workers from physical injury[20]. The International Occupational Hygiene Association (IOHA) characterized OHS as the science of prediction, identification, assessment, and control of hazards arising in or from the working environment that could harm employees' wellbeing and health, considering the potential effect on societies [21]. Therefore, it is considered as the development and upkeep of the degree of workers' physical, mental, and social prosperity in all occupations [22].

Almost half of the total population consists of employees in developed and developing countries. With the developing technology and industrialization, poor working conditions in the workplaces have become a threat to OHS and public health. According to the International Labour Organization (ILO) statistics, about 2.3 million people worldwide die due to occupational accidents or diseases every year, which means that over 6000 deaths occur every day. Annually, 340 million occupational accidents occur, and there are 160 million victims of occupational diseases. The latest statistical data of ILO points out the following critical findings:

(1) Occupational diseases are the main cause of deaths among employees. Only hazardous substances are predicted to lead to 651,279 deaths a year.

(2) Especially the younger and older employees are vulnerable. The population is aging, especially in developed countries; thus, the number of older people working increases day by day, and this situation requires special consideration.

(3) The rate of accidents recorded in the construction industry is disproportionately high [23].

For example, statistics presented in Figure 1 and published in 2015 by EuroStat shows that a "fifth of all workplace accidents happened in the construction sector," but that accidents occur in every sector and job function [24].

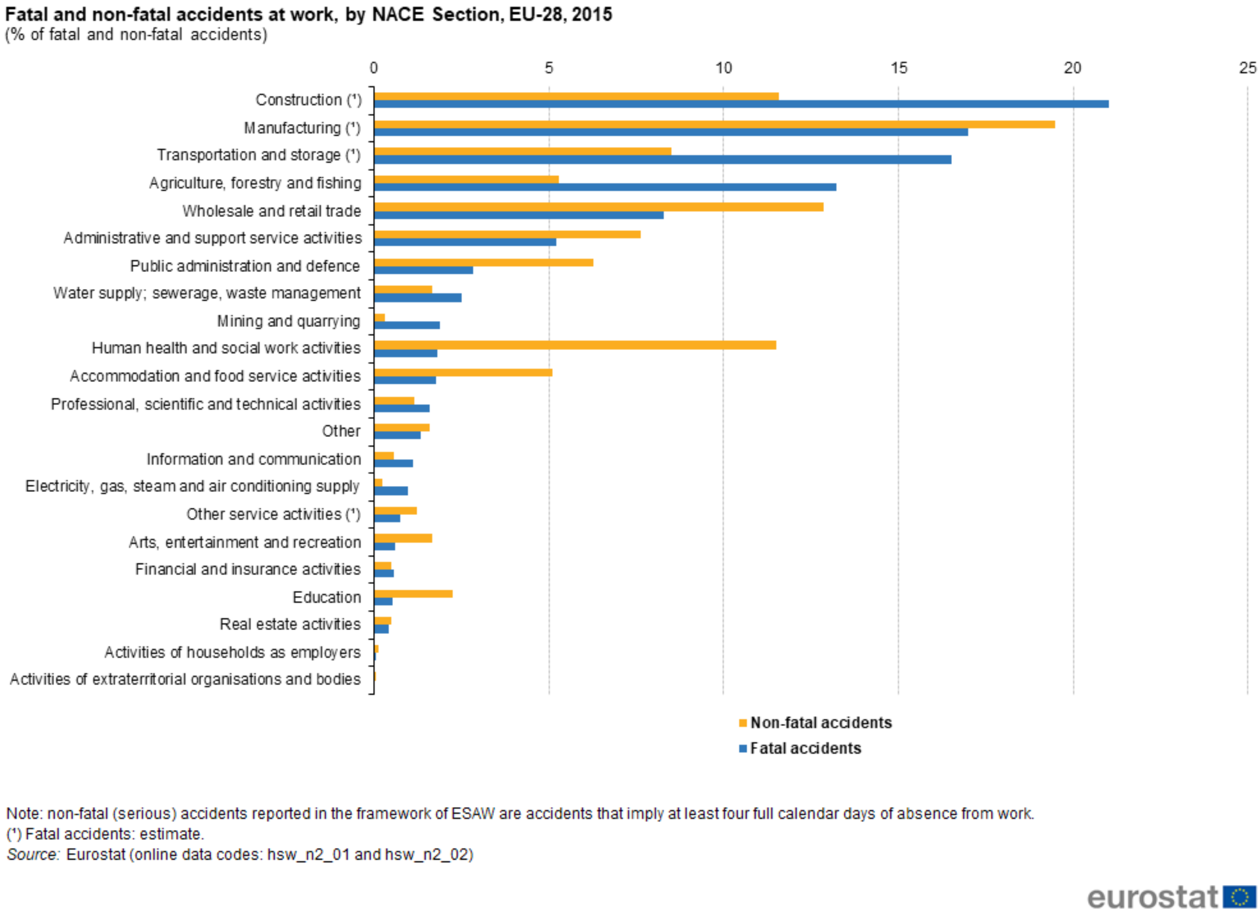

Figure 1. % of fatal and non-fatal accidents at work in European Union countries

All these statistics show that OHS is a fundamental problem, especially for underdeveloped countries, because there is a positive correlation between high OHS achievement and high GNP per capita [1]. Nowadays, industrialized countries are making serious efforts on OHS. These countries are aware that active input in OHS is correlated with the economies' positive development, while low investment in OHS is a hindrance in the economic competition. They are trying to decrease occupational accidents and occupational diseases as low as possible. In this context, OHS's issue in developed countries has become an independent branch of science and constitutes an important part of preventive health services in general public health [25].

According to Willard, the companies' responsibilities to individuals are categorized into two groups, which are distinct and overlapping [26]. These groups are the internal employees and the rest of the world, and in terms of internal employees, one of the issues towards which the firms should direct their policy and efforts is safety and health protection. In outline, the TBL individual component advocates that workers should have the option to rely on a safe workplace that persistently diminishes the danger of injury. This situation is the basis for keeping up a sustainable labor force. Negligence for OHS issues causes an increase in employee turnover, occupational accidents, and compensation claims, which affect the profitability and wealth maximization of shareholders adversely [27]. As a result, providing OHS is both a humanitarian obligation and a legal obligation. The scientific studies revealed that the losses caused by occupational accidents are much more than the expenditures for security measures to ensure OHS. The most important dimension of the situation is the human dimension. Lost time and money can be recovered, but lost lives can never be brought back.

2.4. Social Sustainability-OHS Relation in the Construction Sector

Kaluza et al. stated that it is necessary to manage occupational safety and health effectively to run a successful business [28]. Numerous studies demonstrated that the workforce's general wellbeing and productivity levels

DOI: https://doi.org/10.30564/jbms.v2i1.2591

have a direct relationship with each other [29]. According to Amponsah, protecting the employees against work-related physical and psychological overload, diseases, accidents, and injuries positively correlates with the careful utilization of resources and minimization of avoidable human and material resources loss [27]. OHS practices intend to manage the employees' safety, health, working capacity, and wellbeing, thus providing the continuation of their strategic contribution to the country's socio-economic development. Amponsah thinks that superior OHS policies are significant in terms of sustainable development [27]. These policies provide significant intangible benefits such as improving social and environmental performance, better job satisfaction and commitment of the employees, and the increase of innovation and creativity.

On the contrary, although endeavors were made to promote sustainability in the built environment, very little is done to integrate health and safety (H&S) into sustainability evaluation [30]. According to Molamohamadi, although the main concerns of both of these policies are humans' health and wellbeing, they look at it from different perspectives and attempt to achieve this aim by following different ways [4]. While Sustainable Building (SB) projects consider energy, water and indoor environmental quality-related issues, they pay little attention to OHS aspects [31-32]. This is because the sustainable development and OHS movements have traditionally operated in their own separate spheres, and the synergy between them is little. The German philosopher, Schopenhauer (1788–1860), accentuated the significance of health by expressing that "health is not everything, yet without health, everything is nothing" [33]. From this point of view, even though OHS is the most important part of social sustainability [15, 34], little has been done to evaluate SB's H&S aspects at the project level [35-36]. For Gambatese et al. and Hinze et al., although SB projects offer the potential for improved energy and environmental performance, they are ultimately unsustainable if they compromise the OHS of the Project [15, 32].

3. OHS Activities and Budgeting them at Design Phase

As indicated by Friend and Khon, other than moral issues, OHS should also incorporate economic issues since the costs of the accidents may far outweigh the expenses of managing a working environment healthily and safely [37]. The expenses made for preventing the accidents are the expenses made for all sources utilized by contractors serving in the construction industry to meet OHS's safety and health prerequisites in their on-site applications. Employees in the construction industry should be outfitted with adequate knowledge and essential protection to work under safe conditions [12].

All contractor organizations' expenses, including subcontractors, are also considered investments of safety for taking these protection measures. For safely accomplishing the work, Personal Protective Equipment like helmets, safety boots, safety glasses, and special clothing should be given to the laborers [38]. Moreover, the workplace itself also should be arranged and developed safely. For this, the employers ought to provide safety signs and safety barriers to caution laborers of specific hazards and convey fundamental precautionary measures and emergency activities. It is required to provide adequate fencing, warning boards, and signs to protect the safety and health of the people living near the construction site. In this manner, they can be kept out of the Project area since they are likely not aware of the area's risks [10]. For nearby community safety and health, extra measures like arrangement of alternate walkways, control of the dust and noise pollution, and safely disposing of the hazardous material could be taken [12]. Although these measures will be applied during the construction stage, a critical segment of these measures ought to be planned at the design stage.

Some studies proved a correlation between the design of a project and the number of injuries and fatal incidents in the construction site [15, 39, 40]. According to Valdes-Vasquez, for social sustainability, action should be implemented during construction and operation. However, more advantages can be provided if it is handled during the planning and design stages when it is possible to affect project performance greatly [10]. The aim of the Safety through Design concept, which is also recognized as Design for the Safety of Construction or Prevention through Design, is to reduce construction worker injuries and fatalities besides improving construction worker health [41]. The National Institute for Occupational Safety and Health (NIOSH) recognized this concept as an effective strategy for improving workplace safety [16]. According to this concept, the workers' safety could and should be ensured by the architects and engineers by wiping out possible safety hazards from the construction site at the design stage [42]. So, Safety through Design will contribute to the sustainability of construction projects [15]. Nevertheless, it is not possible to prevent all accidents in the design stage. Thus, implementing a safe and healthy program during construction is also a binding obligation [32, 43].

Providing safety through design also requires budgeting OHS activities. This activity has two sides. While each element designed for preventing an accident during construction or use also requires budgeting them, on the other hand, budgeting a design element makes the implementation of the design element more inevitable. Therefore budgeting the OHS measures is as important as designing them.

The problem is the construction firms' hesitance to implement the required OHS measures that they consider it as an extra economic burden. Numerous construction industry companies lack a safety culture and avoid implementing required measures and battle just with oversimplified and shallow requirements to prevent risks in their on-site implementations. Ascertaining and preparing a budget for providing safety at the start of the construction projects would give a superior comprehension of safety costs during the project's implementation. This improved understanding will reduce the number of accidents, injuries, legal proceedings/sanctions, and reduce trial expenses, and by this means, contribute to the decrease of overall expenditures and, most significantly, the number of life losses. On the other hand, it is seen that budgeting all kinds of measures at the end of the project design phase, and doing the tender or budget planning accordingly, is critical for OHS. This situation seems to be one of the first and most critical steps in preventing construction sector accidents that have material and moral consequences.

Since the construction industry considered accidents as the cost of doing business for a long time, expenses made due to accidents have been involved in the projects' cost estimation. OHS costs are handled in two groups in the construction industry, covering all financial losses in case of an accident on the site [44]. The first group is the expenses of prevention (OHS measures), including the contractor's expenses for preventing accidents [45-46]. The second group is "(direct or indirect) accident costs" arising due to unavoidable accidents that occur despite all measures taken.

Studies considering the OHS costs as part of project costs in the construction sector are not so common. Tan conducted a study comparing the costs of accidents and the costs of a project's safety measures implemented in Turkey. Aminbakhsh, Gündüz and Sönmez assessed the safety risks of a construction project with the Analytic Hierarchy Method in the planning and budgeting stages [48]. A safety cost model, which explains accident prevention benefit-cost analysis, was proposed conceptually by Chalos [49]. Tappura et al. developed an accounting management system based on safety by appointing a value to human life in the cost-benefit analysis [50]. Sousa et al. suggested a new OHS Potential Risk Model in which it is possible to estimate the OHS risk costs statistically [51]. They found that the contractors do not want to lessen their profits by expending money for safety in the construction phase since OHS costs are not calculated in the budgeting phase. Nowadays, a construction project's safety costs are predicted at the very early stages of budgeting by utilizing an "activity-based costing method" [52]. These methods process the work schedule data by utilizing risk assessment methods like the L-Matrix Method and Fine-Kinney Method [46, 53, 54].

The costs of safety staffing, safety training, safety equipment and facilities, safety committee, safety promotion, safety incentive and new technologies, techniques or tools designed for safety comprise the total safety investment cost [32, 45, 56]. Some of these investments are considered basic, and some others as voluntary safety investments. Basic safety investments are the investments to provide minimum safety standards necessary for preventing an accident and required externally due to regulations imposed by the industry or government. These expenses constitute safety investments' compulsory part and involve the cost of safety staffing, the compulsory part of the safety training cost, and the costs of safety equipment and facilities. Voluntary safety investments are the investments made for the occupational accident prevention activities selected by the firms on a project basis. Safety investments made for in-house training activities, safety promotion activities, safety committee activities, and new technologies, techniques, or tools designed for safety activities are involved in voluntary safety activities. So, the total safety investment cost is the sum-up of basic and voluntary safety investment costs [57].

Yılmaz conducted a study in the Turkish construction sector to estimate the OHS measures' compulsory costs at the tender phase [58]. In this study, OHS costs were considered compatible with Teo and Feng's classification, but a new component was included for laboratory examination costs [56]. By utilizing the model proposed in this study, the actual OHS cost of a project belonging to a public building having a total construction area of 12,477.12 m2 was predicted with 95% accuracy at the pre-tender phase.

Yılmaz and Kanıt conducted another study, and by utilizing the same model and its calculation tool, they found that the cost of occupational accidents in the construction industry was 14.52 USD for each m2 construction area in Turkey [59]. They estimated in the same study that the compulsory OHS costs were 8.47 USD/ m2. These data points out that it is possible to provide a decrease of 1.71 USD in social costs by every 1.00 USD investment in OHS in the Turkish construction sector.

Construction cost actually covers the entire lifecycle costs, including the design, projecting, construction, use and destruction of the building. The graph summarizing the system life cycle [60] is adopted in Figure 2 to the construction project management processes.

DOI: https://doi.org/10.30564/jbms.v2i1.2591

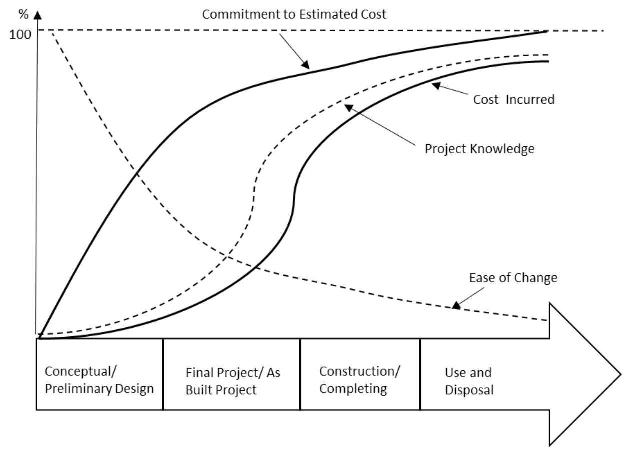

Figure 2. Life cycle, project cost dependence

It can be stated that the most important and expensive component of the building cost is human health. In particular, the cost of production item that causes loss of life can reach an intolerable dimension. Considering the OHS criteria in the phases of conceptual design and implementation projects and preparing Health and Safety Plans, along with the projects, will prevent potential accident risks before occurring during construction. According to the risk hierarchy, which was scientifically proven many times and was supported by the facts, the risks of work accidents can be eliminated to a great extent in the project phase by making a design change, sometimes with the additions in the design and with some low-cost changes in the preliminary design phase of the project. In addition to all these, OHS is considered in the life cycle of a building or engineering structure and is being thought of in the design phase, including maintenance, repair, and renovation [52].

4. Conclusion

As one of today's trendy terms, while too much use of sustainability is sometimes repelling, its importance for the present situation and future of the world is clear considering its origin and meaning. The concept emerged from the uncontrolled consumption-driven development process, which was experienced with the uncontrolled increase in the population, especially after World War 2. This mentioned process caused deterioration of ecological balances, depletion of resources, reduction of water resources, air pollution, the start of the spread of chemicals and heavy metals in nature, global warming, desertification, acid rain, deforestation, ozone depletion along with developments such as increasing poverty and unemployment, unhealthy urbanization, and international inequality; thus sustainability emerged as the name of the development model, which aimed to establish a balance between environment and development, taking into account the human capital and the environment, attentive use of all cultural, social, scientific, human and natural resources of society, and establishing a participatory process from a social perspective.

The concept's importance was easily understood in the construction sector, as one of the most resource-consuming sectors globally, and many new concepts such as green building, sustainable building, and eco-friendly building entered into our life. People need buildings to sustain their lives, and the construction, operation, maintenance, and destruction of these buildings result in a significant environmental impact along with the use of too many resources. According to various studies, it is possible to say that buildings are responsible for 20% of the world's water utilization, 25-40% of total energy utilization, 30-40% of solid waste production and 30-40% of global greenhouse gas emissions. Although all these figures point out mainly the environmental importance of sustainability in the construction sector, it is currently inevitable that sustainability needs to be addressed with its environmental, economic, and social dimensions.

On the other hand, in particular, the social dimension of sustainability has been kept in the background, or it hasn't been cared about consciously. However, when the definitions of social sustainability are considered, it is clear that neither environmental nor economic sustainability can be achieved without social sustainability. According to Colantonio (2009), social sustainability, which covers traditional social policy areas and principles, participation, social capital, economy, environment, and quality of life, deals with how individuals, communities and societies live together and behave to achieve their goals. It could also be defined as the development, which provides working of the community as a whole to achieve the common goals, at the same time, which meets the individuals' everyday needs, such as health, housing, nutrition, cultural expression [7-9]. (Hatfield and Evans, 1996; Gilbert and Stevenson, 1996; Pugh, 1996).

This study dealt with social sustainability, which is the most neglected dimension of sustainability in the construction sector in the context of OHS. Including the minimization of the use of natural resources and the waste generation during the construction, use and demolition stages, considering that the main objective of sustainability is the wellbeing of current and future generations, social sustainability may be evaluated as the most important dimension of sustainability for the construction sector.

Occupational health and safety seem to be the most important elements of ensuring social sustainability in the construction sector. It is evident that a construction project during which workers or those in the environment were damaged, especially they lost their lives, will be not sustainable, no matter how environmentally sensitive buildings were constructed.

This study argues that social sustainability should be aimed first, and social sustainability should first aim to provide occupational health and safety for a sustainable construction sector. It is thought that sustainability goals can be made more realistic only by acting from this point and that a more participative action will be achieved. For this aim, it should be gone beyond the classical approaches, which consider OHS as a discipline completely independent from social sustainability, and the measures aimed at OHS should be budgeted at the design stage. In this way, the cost of these measures will be foreseen from the beginning, and like it is not possible to give up a certain construction item, measures aimed at OHS will cease to be the elements that cannot be given up to maximize profit. Moreover, academic studies have shown that OHS costs to be budgeted are not big figures and even that they are already much smaller than accident costs. On the other hand, it is clear that human life could not be any material equivalent. As a result of considering OHS cost as an integral part of the total cost and taking into account as activity-based in each period from the design stage to the tender stage, it is thought that;

(1) A psychological effect about OHS could be created by increasing the interest of all stakeholders of the construction sector in the first place,

(2) Design criteria could be approached in terms of OHS,

(3) A healthy OHS plan could also be created during the project procurement process,

(4) An OHS working plan that is parallel to the working schedule program could be created,

(5) OHS measures could be deducted from being an expense item that could be easily disregarded by making them more visible and tangible,

(6) In practice, the production inputs required for an activity as well as the OHS measures accompanying that activity, the necessary equipment and installations for field security or personal security would be provided,

(7) The contractor would perform activities related to OHS more voluntarily since OHS expenses will become an expense that is reimbursed for the contractors rather being a general expense,

(8) OHS measures would be controlled more strictly by the administrations since they will become activities for which it will be paid,

(9) Ultimately employees could work in safer and healthier environments, fatal accidents and injuries could be prevented, and it would be contributed to social sustainability and safety culture in the sector.

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  DOI: https://doi.org/10.30564/jbms.v2i1.2591

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REVIEW

Soil Improvement Using Waste Materials: A Review

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ARTICLE INFO

Article history
Received: 30 November 2020
Accepted: 15 December 2020
Published Online: 31 January 2021

Keywords:
Soil stabilisation
Industrial waste materials
Maximum dry density
Unconfined compressive strength
California Bearing Ratio

ABSTRACT

With the industrialisation, industrial byproducts are produced in large quantities and create nuisance to natural habitats. The disposal of these wastes like fly ash, marble powder, construction and demolition (C&D) waste, brick powder, agricultural wastes etc. has become the potential threat to the ecosystem and need some real solutions. The direct disposal of such wastes into open land or water bodies causes circumambient pollution. One of the potential solutions is to utilise these wastes in the construction industry on large scale as subgrade rehab or additive to cement based materials. In the present study, the compaction and strength characteristics of stabilised soil have been studied by using various waste materials i.e. lime, cement, plastic waste, industrial waste, fibre, mushroom waste, wet olive pomace etc. and reviewed. The addition of additives improved the engineering properties of soil significantly.

1. Introduction

With the development in infrastructure sector meanwhile having limited available subgrade soil, engineers are being forced to build structures over the weak soil. To enhance the bearing capacity of soil, additional materials or different techniques are being adopted. The method of improvement of strength characteristics by adding different chemicals or pozzolanic and filler materials is known as stabilisation. Soil stabilisation is a technique in which properties of weak soil is modified or improved by different means. It is being used from ancient time to provide enough strength to foundation to bear the imposed load. The stabilised soil by using additives can be successfully used in road, airport and others works. Earlier; there were many admixtures to stabilise the local soils. From last few years, advancement and demand of economy pushes alternative materials over conventional to pave their way in soil stabilisation. The stabilising materials can be natural or industrial wastes. Agricultural and farming wastes (rice husk ash aka RHA, bagasse ash, chicken eggshells) Fly ash (FA), ground granulated blast furnace slag (GGBFS), marble powder (MP), plastic waste, Portland cement, lime, sand, waste glass, bacteria, construction and demolition (C&D) waste etc. can be used for the purpose. Also, fibrous materials like polypropylene fibre, jute fibre, coir fibre etc. can be used [1]. Rice husk is an agricultural waste and produced during the processing of rice from paddy in rice mills. The ash produced on burning of rice husk is called rice husk ash (RHA). Marble powder is an industrial waste product which is produced during the dimensioning of stones. Lime is calcium oxide or calcium hydroxide. Lime and cement react with the silica and alumina present in the soil to form cementitious materials which

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results into strength and durability enhancement. Lime is used in soil with high clay content [25].

On the other hand, development of the industries plays an important role in the growth of any country. One negative aspect of the industrialisation is the production of industrial byproducts and their disposal issue. The disposal of these industrial wastes causes negative impacts to the environment. Generally, the wastes are directly dumped into the open land area and water bodies consequently creating nuisance and environmental pollution. The scarcity of usable land, transportation cost and taxes are the additional burdens. Therefore, disposal of wastes has become threat to the environment and need a real solution. One of the solutions is to utilise these wastes into the construction industry. These wastes can be used either in the cement or concrete based materials or in problematic soil for soil stabilisation. The utilisation of wastes as additives in soil or concrete not only improve the performance of soil or concrete but also save the natural resources by reducing the disposal problems as well as made ecofriendly and economical end products [68].

In the present study, soil stabilisation using various materials i.e. FA, RHA, lime, cement, fibre, plastic, C&D waste, red mud (RD) etc. has been reviewed. The compaction and strength characteristics have been discussed.

2. Literature Review

The soil improvement or stabilisation by the different natural and industrial waste materials was carried out by the various researchers. The literature review based on previous researches has been given in Table 1.

The swelling potential of clay samples reduced with the addition of nanosilica and its use with EAF slag [26]. The use of plastic strips (0.4%), as reinforcement, increased maximum dry unit weight (MDU), shear strength and CBR. After 0.4% plastic strip, MDU get reduced due to increase in number of plastic strips those restricted the bonding between soil and strips by filling effect of plastic strips at higher percentages. Shear strength increased due to increase in frictional surface between soil particles and plastic strips [20]. 1% plastic waste improved the shear strength due to confinement effect and; development of tensile stress that results in increased cohesion. Plastic waste improved the compression behaviour of clayey soil and negative impact on swelling properties [14].

The addition of RHA reduced DFS may be due to reduction in specific surface and high silica content. Increase in RHA content increased the OMC due to high specific surface area which demand more water for hydration and; decreased MDD due to flocculation and agglomeration of clay particles. RHA (12%) and 6% RHA + 8% OPC increased CBR and UCS values may be due to interlocking of coarse particles and their pozzolanic reaction [1, 18]. The inclusion of sand to clayey soil reduced OMC, and increased MDD and CBR value [29]. RD increased the strength of soil grouting due to pore filling effect. RD (15%) + PC (85%) had maximum UCS value due to consumption of Ca $(OH)_2$ during cement hydration [16].

Table 1. Soil improvement by different materials

Author(s)	Additives	Results
Cucci et al., 2008 [9]	Wet olive pomace	The use of wet olive pomace improved the soil fertility and nutrient content. The wet pomace lowered the pH of soil.
Jafari and Esnaashari, 2012 [10]	Nylon Fibre (0%, 0.5%, 1% and 1.5%) and Lime (0%, 4% and 8%)	Lime at 4% showed more strength than 8%. Increase in lime content decreased MDD and increased the OMC. Addition of fibre reduced MDD and OMC. Fibre upto 1.5% increased the UCS value beyond that it decreased. Increase in FT cycles decreased the UCS values.
Guo et al., 2013 [11]	Mushroom waste	Mushroom waste improved the soil properties.
Ural et al., 2014 [12]	Marble dust (MD)	Soil with MD showed better performance. MD at 5% attained maximum UCS value.
Sharma and Hymavathi, 2016 [13]	Fly ash, C&D, waste lime	Differential free swell (DFS) and MDD decreased while, pH, UCS and soaked CBR values increased with the use of additives.
SoltaniJigheh, 2016 [14]	Plastic waste (0%, 0.5%, 1%, 1.5% and 3%)	Plastic waste had insignificant effect on compaction characteristics of clayey soil. Plastic waste improved the compression behaviour of clayey soil and negative impact on swelling properties.
Hasan et al., 2016 [15]	Ground granulated blast furnace slag (GGBFS) and recycled construction waste (CW) in Bentonite clay	The inclusion of GGBFS and CW increased the UCS. CW alone produced insignificant improvement and GGBFS alone increased the UCS significantly.
Çelik, 2016 [16]	Red mud (RD) at 025%@5% and 100%; and Portland cement (PC) at0% and 75100%@5% in soil grouting	RD increased the strength of soil in grouting. RD (15%) + PC (85%) helped to attain maximum UCS value.
Maity et al., 2017 [17]	RHA (0%, 2%, 4%, 6% and 8%) and ordinary Portland cement (OPC) (2%, 4%, 6% and 8%)	Increase in RHA content increased OMC and decreased MDD. RHA and OPC improved the UCS and CBR values accordingly.
Rahgozar et al., 2017 [18]	Natural fibre (Jute fibre, coir fibre and sabai grass) at 1%, 1.5%, 2% and 2.5%	Increase in fibre content decreased the MDD and increased OMC. Increase in fibre upto 2% increased the CBR and UCS.

DOI: https://doi.org/10.30564/jbms.v2i1.2641

Author(s)	Additives	Results
Pathania and Soni, 2017 [19]	Quarry dust in clayey soil (025%@5%)	Quarry dust increased MDD and decreased OMC and PI. Quarry dust at 20% had maximum UCS value.
Öncü and Bilsel, 2018 [20]	Marble powder (MP), Marble dust (MD)	MP (10%) and MD (5%) were found the optimum content for minimum swellshrink potential and compression index, high UCS and flexural strength. MDD was found increased whereas OMC was reduced.
Peddaiah et al., 2018 [21]	Plastic bottle strip (0.2%, 0.4%, 0.6% and 0.8%) in silty sand	The use of plastic strip (0.4%) as reinforcement increased maximum dry unit weight (MDU), shear strength and CBR.
Noorzad and Motevalian, 2018 [22]	Lime (4%, 6%, 8%, 19% and 12%), steel and copper sludge	Addition of lime and sludge increased the strength with curing time. Steel sludge was found better in improving the strength than copper sludge.
Khazaei Hossein Moayedi, 2019 [23]	Chemical waste and lime stabiliser (4%, 6%, 8%, 10% and 12% each)	Chemical waste and lime improved the Atterberg limits, UCS and shear strength. Addition of chemical waste and lime increased the pH value.
Sharma and Sharma, 2019 [24]	Crushed C&D waste (4%. 8%, 12%, 16%, 20%, 24% and 28%)	C&D waste in soil improved the stressstrain and volumetric behaviour. Increase in C&D waste increased the pH.
Parihar et al., 2019 [25]	Soda lime glass (0%, 3%, 6%, 9% and 12%) and Microfine slag (MFS)	Addition of waste glass increased PL and shrinkage limit. Waste glass upto 9% increased MDD and decreased OMC afterwards opposite trend was observed.
Bibak et al., 2019 [26]	Lime, waste material, sodium silicate	Lime (6%), industrial waste (6%) and sodium silicate (1.5%) improved the strength of stabilised soil. Additives increased MDD and pH value whereas, reduced the rate of consolidation.
Kumar et al., 2019 [4]	ESP, PPF and NaCl	Plastic properties were found to be improved with the inclusion of air entrainer.
Kumar et al., 2019 [27]	ESP, PPF and NaCl	Strength properties of Himalayan soil improved with the addition of ESP, PPF and NaCl under both normal and harsh conditions.
Kumar et al., 2019 [28]	ESP, PPF and NaCl	The mass loss of soil under FT cycles was within permissible limits.
Bekhiti et al., 2019 [29]	Waste tire rubber fibre (0%, 0.5%, 1% and 2%) and cement (5%, 7.5% and 10%) in bentonite clay soil	Both additives reduced LL, MDD and swelling characteristics and increased UCS.
Choobbasti et al., 2019 [30]	Nano calcium carbonate (0%, 0.4%, 0.8% and 1.2%) as stabilizer and carpet waste fibre (0%, 0.2%, 0.4% and 0.6%) in clayey soil	The inclusion of nano particles reduced LL and increased PL. The combination of additives improved the strength. Carpet fibre upto 0.2% improved the residual strength and velocity of ultrasonic waves. The strength increased due to chemical reaction that results into formation of cementitious materials.
Liang et al., 2020 [31]	Municipal solid waste incineration fly ash (MSWIFA) in cement stabilised soil	The addition of cement and MSWIFA enhanced the UCS and internal friction angle.
Kumar and Kumar, 2020 [32]	Electronic (e) waste at 3%, 6%, 9% and 12%	ewaste increased the LL, OMC and UCS.
Shahsavani et al., 2020 [33]	Nanosilica and EAF slag in expansive clay	The swelling potential of clay sample consisting nanosilica alone and nanosilica + EAF slag was reduced.
Sharma and Sharma, 2020 [1]	RHA and C&D waste with or without lime in clayey soil	The addition of RHA reduced DFS. RHA increased the OMC and reduced the MDD of the soil. RHA (12%) and Lime (5%) increased the CBR value. C&D waste + lime improved the UCS, CBR and resilient modulus of clayey soil.
Aydin et al., 2020 [34]	Calcite marble powder (CMP) and dolomitic marble powder (DMP) as 5%, 10%, 20%, 30% and 50% each in fine grained soil	Upto 5% MP, value of q_u and E_u increased afterwards it reduced. The mass loss of stabilised soil reduced with increase in MP irrespective of MP and soil type; but found increased with FT cycles. Addition of MP enhanced FT resistance.
Deboucha et al., 2020 [35]	Cement (PC) at 1.5% and 2%, marble dust (MD) at 2%, 3%, 4% and 5% and ceramic waste (CW) at 5%, 10% and 15% in pavement sub base layer	The additives increased the CBR value. PC and PC+CW showed higher CBR than CW and MD only.
Sharma, 2020 [36]	Sand, FA and waste ceramic in clayey soil	Addition of additive improved the soil characteristics. Addition of sand to clayey soil reduced OMC with increased MDD and CBR values.
Bagriacik and Mahmutluoglu, 2020 [37]	Construction demolition waste (C&DW) at 222%@2%and cement (CMT) at 28%@2%	C&DW (16%) attained the highest strength. CMT+CDW increased the strength.
Rivera et al., 2020 [38]	Fly ash	Soil with maximum content of sand had higher dry density. The alkali activated stabilised soil block as raw materials improved the soil properties.
Jishnu et al., 2020 [39]	Natural fibres Coconut leaflet (1%, 2% and 3%)	Shear strength ratio of reinforced soil decreased with increase in confining pressure.

CBR value decreased beyond 10% CW. CW+OPC increased the bearing capacity due to hydration reaction of cement and lime content [28]. C&D waste (24%) and CDW (16%) increased CBR value [1, 30]. Addition of C&D waste decreased the volumetric strain, cohesion value and angle of shearing resistance; and increased the strength ratio and stiffness. Increase in C&D waste content increased the pH due to its alkaline nature. The optimum content of C&D waste was 24% in expansive soil [23]. The inclusion of GGBFS and CW increased UCS and optimum content was 5% and 20% respectively. CW alone had insignificant improvement and GGBFS increased UCS due to its cementitious nature [15]. The addition of cement and MSWIFA enhanced the UCS and internal friction angle [31]. Electronic waste increased the LL, OMC and UCS [32].

Mushroom waste improved the soil properties. The full decomposition of mushroom waste improved the soil quality and these effects deteriorate with time [11].

MD at 5% had maximum UCS value. Cured specimens had higher UCS than uncured specimens [12]. MD improved the soil characteristics due to higher content of CaO [28]. MP (10%) and MD (5%) were found optimised for swellshrink potential, compression index, high UCS and flexural strength. MDD increased and OMC reduced with increase in MP [19]. Upto 5% MP, value of UCS and E_u increased afterwards values started to reduce. The strength of soil increased with MP after 7 days curing due to pozzolanic effect. The mass loss of stabilised soil reduced with increase in MP. Incorporated waste enhanced the freezethaw resistance of stabilised soil [27]. Quarry dust increased MDD and UCS; whereas, decreased the OMC and PI (Fig. 1) [19]. Addition of lime (6%), industrial waste (6%) and sodium silicate (1.5%) improved the MDD and strength of stabilised soil due to hydration reaction of lime and chemical action of sodium silicate which reduced the porosity. The addition of additives reduced the rate of consolidation and increased the pH value [25]. Lime (5%) increased the CBR value due to cation exchange reaction between soil and lime which bind the soil particles [1]. Addition of lime and sludge increased the strength. Steel sludge was found better than copper sludge in improving the strength. Addition of lime in soil reduced the LL and PL due to cation exchange. MDD reduced due to low specific gravity of lime and integration of soil structure that increased the voids between soil particles. Increase in OMC was found due to lime hydration [21]. Chemical waste and lime improved the Atterberg limits, UCS and shear strength. Lime was proved to be more effective than chemical waste. Addition of chemical waste and lime increased the pH value of stabilised soil [22]. Increase in lime content and fibre individually decreased MDD due to its low specific gravity but increased the OMC, and lime was found predominant than fibre in compaction improving the compaction properties. Fibre upto 1.5% increased the UCS value beyond that it decreased due to agglomeration of fibre at higher content. Increase in FT cycles decreased the UCS values [10].

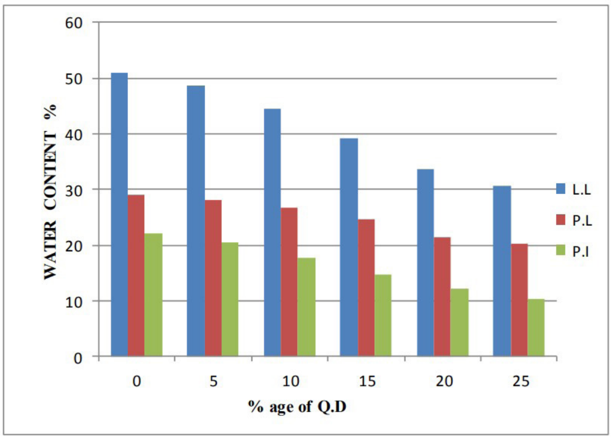

Figure 1. Variation in plastic properties at various percentages of quarry dust

Addition of waste glass improved plastic and compaction properties of the subjected soil. The improvement of MDD with waste glass was due to formation of good cohesive matrix between fine clay and slit particles. Both additives upto 6% in soil improved the unsoaked CBR [24]. Soil with maximum content of sand had higher dry density due to low permeable pores and lower water absorption. The alkali activated stabilised soil block as raw materials improved the soil properties i.e. MDD, UCS and lowered the water absorption [31]. Differential free swell (DFS) and MDD decreased; and pH, UCS and soaked CBR values increased after addition of FA, C&D and lime. FA, C&D and lime decreased DFS due to pozzolanic and non-swelling nature of FA, increase in coarser particles and reduction in specific surface area cumulatively. FA was better in reducing DFS than C&D and lime. Lime at 4% was found as the optimum content for soil stabilisation. The reduction in MDD was more for lime followed by FA and C&D waste. OMC increased with FA and lime but decreased by C&D waste. FA increased the UCS due to its pozzolanic nature which formed cementitious compounds and good bonding. C&D increased UCS due to pozzolanic behaviour and lime due to chemical reactions between soil particles and lime that result into good bonding. UCS improvement was more in case of lime than that of FA and C&D waste. FA and lime increased the CBR value due to interlocking of coarse particles and cation exchange reaction, respectively. C&D waste increased CBR value due to presence of sand particles which mobilized the angle on internal friction and increased the strength [13].

Increase in fibre content decreased the MDD due to its low specific weight and increased OMC due to its high waterabsorptioncapacity. Sabai grass fibre had maximum reduction in MDD and increase in OMC than others. Increase in fibre upto 2% increased the CBR and UCS val-

DOI: https://doi.org/10.30564/jbms.v2i1.2641

ues afterwards diminished due to loss in contact between fibre and soil. Among all fibre, coir fibre was found most efficient in improving the CBR and UCS values [17]. Shear strength ratio of reinforced soil decreased with increase in confining pressure. The soilfibre interaction exhibits bulging behaviour and found to be good additive in enhancing the engineering properties [32]. The use of wet olive pomace improved the soil fertility and nutrient content but lowered the pH of soil due to high buffer power of soil [9]. The additives improved the strength due to chemical reaction that results into formation of cementitious materials. Carpet fibre upto 0.2% had optimum content in improving the soil characteristics [30]. Plastic characteristics, strength and mass loss of Himalayan soil under FT cycles were improved with the usage of optimum content of PPF, sodium chloride and ESP due to high thermal properties of fibre and also bulging behavior of PPF; chemical action of NaCl that consequently changed the clayey soil to sodium clay which depicted the higher strength and filling effect of ESP respectively (Fig. 2, Fig. 3 and Fig. 4) [4, 27, 28].

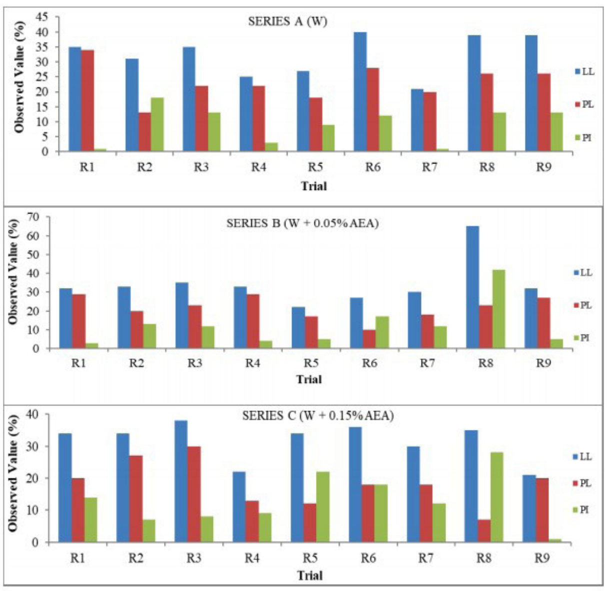

Figure 2. Variation in plastic properties at various percentages of ESP, PPF and NaCl with air entrainer

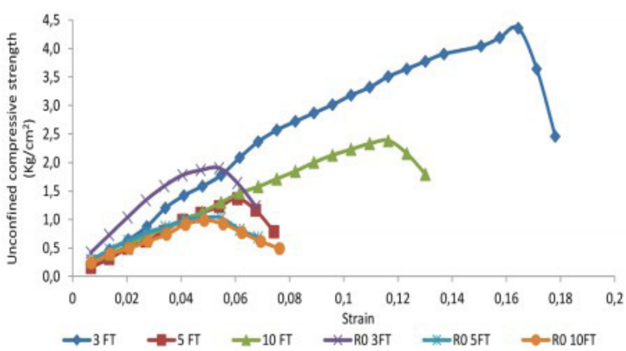

Figure 3. Variation in UCS values after various FT cycles

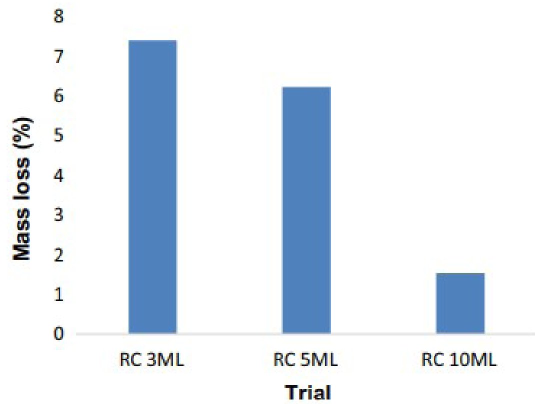

Figure 4. Variation in mass loss after various FT cycles

The inclusion of nano particles reduced LL and increased PL. Both additives reduced LL due to nonabsorbing behavior of fibre and absorbing nature of cement, MDD due to lower density of additives especially rubber fibre and swelling characteristics and increased UCS [29].

3. Conclusions

The soil stabilisation has become the need to make the foundation or subgrade strong enough to bear the loads. The soil stabilisation is being done by addition of many materials. The various materials used to improve the properties of soil have been reviewed and following findings have been derived from the above study:

(1) Cement and C&D waste in soil improved the strength characteristics of soil due to formation of cementitious materials. C&D waste increased the pH value. The improved soil can be used in low volume traffic roads and embankment stability.

(2) Plastic waste improved the load carrying capacity. Plastic waste in clayey soil can be used as lightweight construction materials as it improves the strength and compressibility behaviour of fine soils.

(3) Addition of RHA increased the OMC and decreased MDD. RHA increased the strength of soil due to its pozzolanic nature.

(4) Mushroom waste improved the soil properties significantly.

(5) MP and lime improved the soil characteristics due to higher content of CaO in their formation.

(6) The alkali activated stabilised soil block as raw materials improved the soil properties and reduced the greenhouse gas emission and renewable resources consumption as compared to concrete paving blocks.

(7) Fibre enhanced the tensile strength due to their bulging behaviour.

 DOI: https://doi.org/10.30564/jbms.v2i1.2641

(8) The use of wet olive pomace improved the soil fertility but lowered the pH of soil.

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Journal of Building Material Science
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ARTICLE

Optimization Model and Pollution Treatment of Sintering Ore Distribution

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ARTICLE INFO

Article history
Received: 30 November 2020
Accepted: 10 January 2021
Published Online: 31 January 2021

Keywords:
Sinter blending
Optimized blending
TOPSIS
Desulfurization and emission reduction

ABSTRACT

Sintering process plays an important role in iron and steel smelting process. The subsequent production of blast furnace ironmaking is directly affected by the quality of sinter. Among them, the proportion of raw materials and the advanced degree of sintering process are the two main factors affecting the quality of sinter. Because the control parameters of sintering process are too many and the physical and chemical process is too complex, it is difficult to establish and control the model accurately. Therefore, workers have long relied on experience to set temperature and other factors to engage in production, resulting in the quality of sinter is unstable, the cost is not easy to be controlled. Moreover, the flue gas produced in the sintering process will have different effects on the environment. Through the data analysis of the ore distribution scheme and the results of the physicochemical analysis of sinter in a steel plant, two aspects of the work are completed: one is to establish the optimal model of the cost of the sintering process, and the most suitable temperature for the sintering process. The second is the analysis of harmful components produced in sintering process.

1. Introduction

Because sintering can greatly improve the quality and value of ore, the process of steel production in domestic steel mills is mostly carried out by sintering process. Through sintering process, the scarce components in natural ore are enriched, and the ore is transformed into artificial rich ore with higher quality and value, so as to meet the demand for rich ore resources in industrial production. Therefore, sintering process re-industrial production occupies an indispensable position. If the sintering process can be optimized, and the optimum ambient temperature of sintering process can be predicted. The cost of sintering process can be significantly reduced, and the quality of sinter can be significantly improved to provide more high quality materials for industrial production. At the same time, due to the rich sulfur element in the mineral raw materials of the sintering process, the release of sulfur element will produce a large amount of pollutants to the environment during the sintering process. According to the statistics of relevant departments, the sintering process is SO in production$_2$Emissions account for about 80 per cent of total steel production[1]. If desulphurization is achieved in the sintering process, the pollution discharge

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DOI: https://doi.org/10.30564/jbms.v2i1.2718

of the sintering process and the quality of the sinter will be improved considerably. In this paper, the optimal ore blending model of sintering process and the treatment of subsequent flue gas pollutants are realized by optimizing the algorithm and the treatment of polluting compounds such as sulfur-containing elements.

2. Sintering Process

2.1 Sintering Process

Sintering is an important link in metallurgical process. If we want to improve sintering process, optimize sintering blending and establish optimal temperature prediction model, we must have a certain degree of understanding of sintering process. Figure 1 is a typical sintering process flow chart.

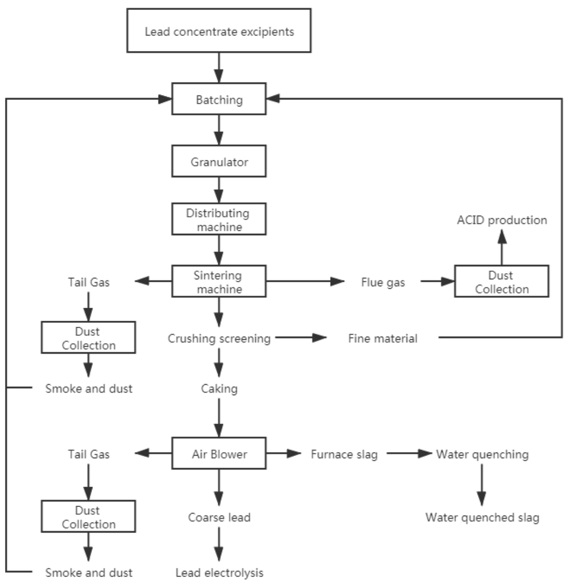


Figure 1. Typical sintering process

According to the flow chart of the sintering process, the main energy consumption types in the sintering process are electric energy, water energy, gas and solid fuel. In the process of sintering, the main place of these energy sources is to provide suitable temperature for sintering process, so that all kinds of elemental compounds in mineral raw materials can be successfully reacted and enriched. At the same time, in each process of sintering process, a large amount of tail gas, smoke and dust produced and the treatment of these pollutants are all necessary processes for sintering process to realize the quality of sinter. Therefore, in order to improve the quality of sinter and reduce the environmental pollution of sintering process, the temperature prediction is chosen as the core to achieve the established goal of reducing sintering cost and the removal of nitrogen and sulfur compounds.

2.2 Analysis of Raw Material Composition of Sinter

2.2.1 Design Experiments

Because of the limitation of the condition, the practical experiment can not be carried out in this paper, so the sintering material used in the field sintering of a steel plant is chosen as the main body of the analysis.

Table 1. Chemical composition of field sinter (mass fraction) [2]

Name of name	TFe	FeO	CaO	SiO_2	MgO	Al_2O_3	TiO_2
Chiron A	64.75	0.14	0.00	2.35	0.24	1.60	0.150
Chiron B	62.70	0.29	0.07	4.15	0.21	2.16	0.120
Chiron C	57.53	0.40	0.68	6.42	0.59	3.11	0.300
Chiron D	61.59	0.27	0.46	5.55	0.55	1.18	0.260
magnetite A	65.51	19.41	0.24	6.07	0.61	0.44	0.150
magnetite B	66.33	23.52	0.29	5.55	0.72	0.39	0.081
magnetite C	63.92	27.92	1.49	1.16	3.53	0.61	2.480

Table 2. Design of experimental scheme for ore blending

Programme series	Mineral types	Minimum ratio
No .1	Chiron A	10
No .2	Chiron B	10
3 No. No	magnetite A	5

Table 3. Theoretical Chemical Composition and Basic Characteristics of Sintering of Mixed Minerals [3]

	Characteristics of sintering foundation				
	Mineral powder ratio	Assimilation temperature	Liquid phase liquidity	Strength of bonding phase	Continuous crystal strength
No .1	10	1257.0	0.291	1412.772	523.735
	15	1258.3	0.237	1450.885	614.782
	21.12	1260.7	0.211	1552.233	745.789
	25	1262.3	0.188	1580.035	920.213
	30	1266.7	0.211	1626.549	974.041
No .2	10	1259.0	0.283	1256.663	545.628
	15	1261.0	0.237	1295.431	580.020
	20	1262.0	0.182	1483.557	619.230
	25	1262.0	0.173	1417.383	718.792
	30	1261.3	0.134	1386.552	936.525
	35	1260.3	0.054	1306.269	1116.883
No .3	5	1259.7	0.138	2329.156	1080.717
	10	1264.7	0.107	1807.847	801.607
	13.3	1260.7	0.211	1700.381	745.789
	20	1264.0	0.615	1655.137	770.241
	25	1269.3	0.907	1302.965	759.943
	30	1270.7	1.241	1257.197	729.652

DOI: https://doi.org/10.30564/jbms.v2i1.2718

From the data in Table 1, we can see the composition and content of various elemental compounds in different kinds of ores. Based on this, three groups of sintering cup experiments were designed, and the properties of sintered mineral products were compared with those of different blending ratios. Table 3 shows the experimental data of three ore blending methods under different ore powder ratios.

2.2.2 Topsis Treatment of Priority Properties and Scores of Sintering Products in Each Group

After the data in Table 3 are obtained from the experiment, the Topsis algorithm is used to compare the quality of sinter obtained in 17 groups of experiments. Considering the cost of sintering process and the quality of sinter. The assimilation temperature of the sintered ore is taken as a great type to improve its metal properties, the liquid phase fluidity is taken as a minimum type, so that the difficulty of removing the unrelated impurity elements in the sintering process can be reduced to reduce the cost, and the bonding phase strength and the continuous crystal strength are set as very small and maximum, respectively. Implementation using Matlab code:

Forward formula: $M=\max\{|x_i- x_{best}|\}$, $x_{Average}=1-(|xi-xbest|)/ M$.

(1) Bring the two columns of data in Table 2 into the forward formula, and get the corresponding M value of each data;

(2) To add tables to the work area X, import the sinter data from 17 groups of experiments in Table 3 into X; table

(3) Import Topsis code:

(4) The code can realize the calculation of the priority of 17 groups of data. The results are as follows:

Normalized Matrix			
0.241509555	0.237275251	0.261364074	0.159866718
0.241759327	0.250762476	0.250493774	0.187658225
0.242220443	0.257256325	0.221588068	0.227647264
0.242527853	0.263000884	0.213658593	0.280889061
0.243373233	0.257256325	0.200392224	0.297319709
0.241893819	0.239273358	0.305888295	0.166549414
0.242278082	0.250762476	0.294831181	0.17704735
0.242470214	0.264499464	0.241175314	0.189015948
0.242470214	0.266747335	0.260048959	0.219406604
0.242335722	0.276488108	0.268842343	0.285868193
0.24214359	0.296469182	0.291740049	0.340921305
0.242028311	0.275489055	0	0.329881867
0.242988969	0.283231721	0.148683787	0.244685347
0.242220443	0.257256325	0.179334423	0.227647264
0.242854477	0.156351902	0.192238572	0.235111078
0.243872775	0.083420983	0.292682391	0.231967681
0.24414176	0	0.305735992	0.222721549

Figure 2.

Table 4

Prioritization of experimental data									
Group	17	16	15	12	5	11	4	1	14
	6	10	3	13	2	7	9	8	

2.2.3 Analytic Hierarchy Process Addressing the Weight of Each Nature

From the experimental data in figure 3, the priority of each experimental data can be more accurate to judge the four attributes of sinter, which occupy an important layer in the overall basic performance of sinter. The weight of the four basic attributes in the overall metallurgical performance can be calculated respectively:

(1) Constructing Relational Matrix:

	Assimilation temperature	Liquid phase liquidity	Strength of bonding phase	Continuous crystal strength
Assimilation temperature	1	3	5	4
Liquid phase liquidity	1/3	1	2	1.50
Strength of bonding phase	0.2	0.5	1	0.80
Continuous crystal strength	0.25	0.75	1.25	1

(2) use the Matlab function to solve the corresponding weights of four attributes:

Four attributes are 3. weighted:

By the above code, the CR value of the relation matrix is less than 0.10, so the weight result is consistent, and the relation matrix does not need to be modified. and the overall weights of the four attributes obtained are :0.5553,0.1997,0.1062,0.1388.

2.2.4 Fitting and Predicting Optimal Model for Sinter Blending

It can be inferred from the above process that the assimilation temperature and liquid phase fluidity account for the larger weight in the basic attributes of sintering condition, so the optimum ratio of raw materials in sinter blending is inferred based on the two attributes.

(1) A of hematite

The two groups of data with the highest weight in Table 2 were fitted with the independent variable of the proportion of powder distribution

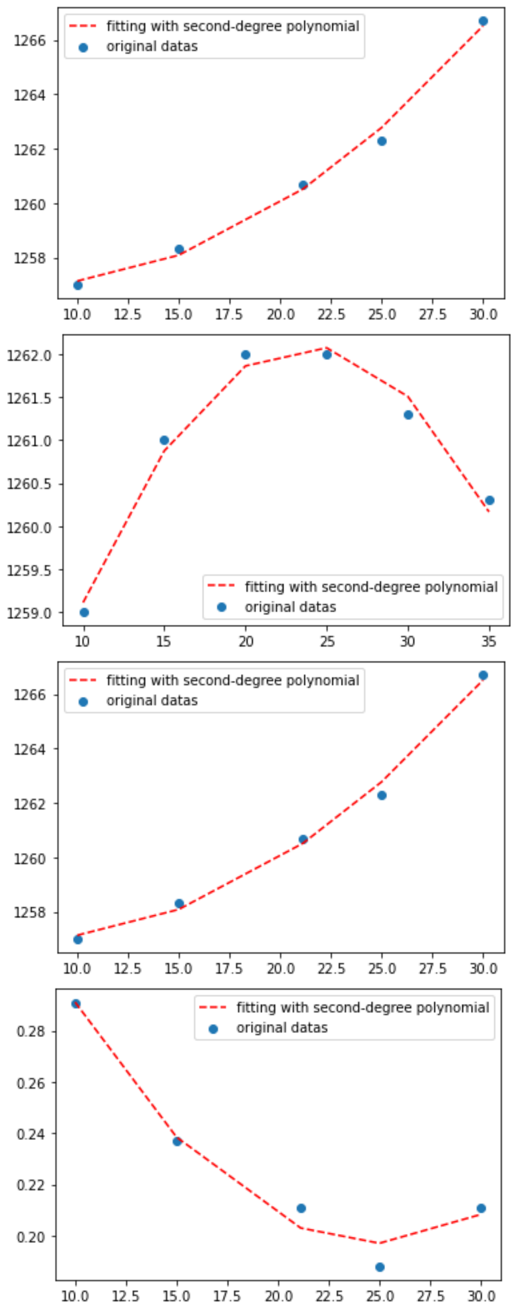
Assimilation temperature:

And the expression of the corresponding fitting function is x :0.01859^2 0.2747 x +1258

By the same token, the liquid phase fluidity function is x :0.0004263^2 0.02119 x +0.4605

And the corresponding images are:

DOI: https://doi.org/10.30564/jbms.v2i1.2718



It can be obtained from the analysis of the diagram that when the ratio of powder distribution is 15-25, the assimilation temperature of sinter is higher and the liquid phase fluidity of sintered products is low, that is, the quality of sintered mineral products is relatively high and the energy consumption cost of sintering process is relatively low.

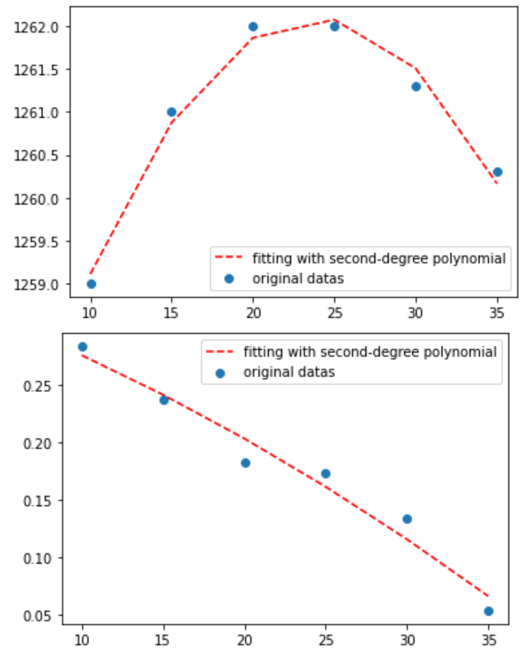
(2) A of hematite B, magnetite

According to the fitting process of the two attributes of the above hematite A, the fitting process can be obtained:

Assimilation temperature :$-0.01557\ x^2 +0.743\ x +1253$

Liquid fluidity :$-7.571*10^{-5}\ x^2 -0.004953\ x +0.3325$

And the corresponding images of the two groups of fitting functions are as follows:

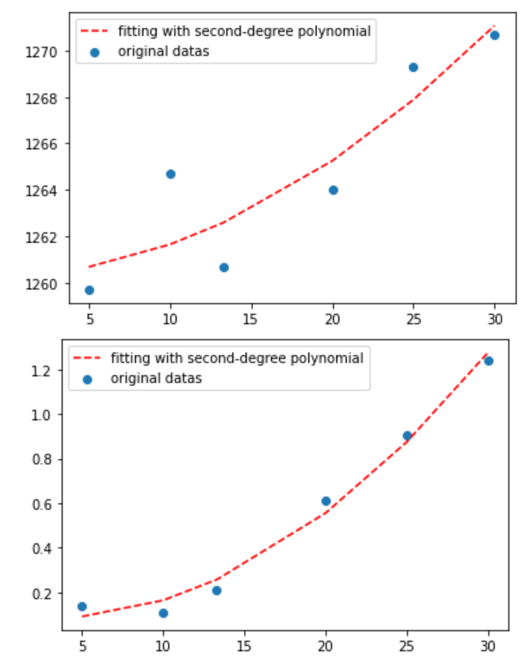


A fitting function corresponding to two sets of data in magnetite A is:

Assimilation temperature: $x\ 0.01114^2\ +0.02623\ x\ +1260$

Liquid fluidity: $x\ 0.001642^2\ 0.01009\ x\ +0.101$

The corresponding image of the fitting function is:



The fitting curve shows that the metal properties A hematite B and magnet ore have higher assimilation temperature and lower liquid phase fluidity when the powder ratio is 20-27% and 9-13%, respectively.

3. Flue Gas Treatment

Because the raw materials of sintering process contain a large number of sulfur compounds, most of the pollution in sintering process is flue gas pollution, among which harmful gas pollutants mainly include SO2, NOX and so on.

3.1 Sulfur Compounds in Flue Gas

3.1.1 Produce

SO of sulfur compounds in flue gas_2During the sintering process, the main way is the oxidation reaction of sulfide (FeS2,FeS) in iron powder [4]:

$$2FeS_2\ O +11/2_2 =Fe_2O_3 +4\ SO_2 \quad (1)$$

$$2FeS_2 =2\ FeS +2\ S \quad (2)$$

$$S+O_2 =SO_2 \quad (3)$$

$$2FeS +7/2FeS +O_2 =Fe_2O_3\ SO +2_2 \quad (4)$$

However, most of the sulfates in iron powder release gaseous sulfide by decomposition reaction during sintering [5]. Organic sulfur in solid fuels is oxidized to form gaseous sulfides.

3.1.2 Handling

(1) Emission reductions at source:

The main pollution elements in sintering flue gas are mostly from sintering raw materials, so the content of gaseous pollutants in flue gas can be greatly reduced by controlling the composition of sintering raw materials, such as reducing the ratio of coke powder and quicklime, adjusting the ratio of sintered iron materials, or reasonably controlling the moisture content of mixture, so as to achieve the emission reduction at the source [6]. Long Hongming et al [7] SO based on sintering $process_2$ A new method for desulphurization by adding urea solid particles evenly in the fault layer of sintered material is proposed. An industrial test shows that the ratio of urea to SO is 0.09% in the super-wet layer $mixture_2$The emission reduction has great effect. Su Yudong [8]. By increasing the water content of the mixture, increasing the height of the sintered material layer and the basicity of quicklime, and reducing the ratio of coke powder and anthracite in the mixture, the NO emission concentration can be reduced by about 20% under the premise of ensuring the quality of sinter.

(2) Absorption degradation

For now, SO_2The treatment technology has been very perfect, including dry, wet and semi-dry desulfurization process. Among them, lime-gypsum wet desulfurization process is the most widely used, the best effect, the most mature technology desulfurization method. Its actual process is as follows:

Limestone (CaCO) is generally used in the lime-gypsum $process_3$) or lime (CaO) as a desulfurization absorbent, crushing and grinding limestone into powdered and mixed water to form an absorbent slurry, which is fed into a desulfurization absorber. At the absorption tower, the absorbent slurry is mixed with the flue gas, and the SO in the flue gas_2By CaCO with $slurry_3$and oxygen pumped into the air for chemical reactions to form gypsum (CaSO); and_4The slurry is removed [9]. The gypsum slurry formed is treated by a vacuum belt dehydrator to obtain gypsum [10].

Main chemical reaction formula of lime-gypsum desulphurization process [11]. As follows:

$$CaO+H_2O \rightarrow Ca\ (O\ H)_2 \quad (5)$$

$$Ca\ (OH)_2+SO_2H +1/2_2O \rightarrow CaSO_3::1/2\ H_2O+H_2O \quad (6)$$

$$Ca\ (OH)_2+SO_3+H_2O \rightarrow CaSO_4H\ 2_2O \quad (7)$$

$$CaSO_3::1/2\ H_2O\ O+1/2_2H +3/2_2O \rightarrow CaSO_4H\ 2_2O \quad (8)$$

4. Conclusions

4.1 Conclusion

(1) in the basic properties of sintered mineral products, the higher weight is its assimilation temperature and liquid phase fluidity.

(2) from the above fitting images, the metallurgical properties of the sintered products are superior when the proportion of powder A hematite is 15-25. The ratio of powder distribution of hematite B and magnetite A can be reduced to 20-27% and 9-13% respectively, thus further improving the metallurgical properties of sintering products and reducing the energy consumption cost of sintering process.

4.2 Comprehensive Consideration and Prospect of Desulfurization Process in Sintering Process

(1) Gaseous pollutants in sintered flue gas mainly include SO_2NOx and dioxins[12]. As China sinter environmental protection standards are gradually improved, the SO is_2NOx and dioxin emissions are severely restricted. Current SO in flue gas_2The removal technology is mature,

DOI: https://doi.org/10.30564/jbms.v2i1.2718

including dry, wet and semi-dry. Compared with wet desulfurization process, semi-dry desulfurization process has no acid substance and no waste water discharge, which is more in line with environmental protection requirements. The more mature technology NOx flue gas is SCR denitrification process [13]. The rational reuse of desulphurization gypsum will be the focus of future research on sintering flue gas desulfurization technology.

(2) Consider the SO of sintered flue $gas_2$and NO_xCollaborative emission reduction is the main direction of scientific research in the future. Some domestic iron and steel enterprises have adopted activated carbon or activated coke technology, but because of the high investment cost, it has not been widely used. Therefore, how to reduce the investment and operation cost of comprehensive treatment technology of flue gas pollutants and further improve the adsorption effect of activated carbon or activated coke is the key to the wide application of existing technology. Combined with the existing terminal treatment technology will be an important direction in the future.

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Journal of Building Material Science
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ARTICLE

The Effect of Various Polynaphthalene Sulfonate Based Superplasticizers on the Workability of Reactive Powder Concrete

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ARTICLE INFO

Article history
Received: 25 December 2020
Accepted: 10 January 2021
Published Online: 31 January 2021

Keywords:
Reactive powder concrete
Ultra high strength concrete
Superplasticizer
Workability

ABSTRACT

A superplasticizer is a type of chemical admixture used to alter the workability (viscosity) of fresh concrete. The workability of fresh concrete is often of particular importance when the water-to-cement (w/c) ratio is low and a particular workability is desired. Reactive Powder Concrete (RPC) is a high-strength concrete formulated to provide compressive strengths exceeding 130MPa and made of primarily powders. RPC materials typically have a very low w/c, which requires the use of a chemical admixture in order to create a material that is easier to place, handle and consolidate. Superplasticizer are commonly used for this purpose. Superplasticizers are developed from different formulations, the most common being Polycarboxylate Ether (PCE), Polymelamine Sulfonate (PMS), and Polynaphthalene Sulfonate (PNS). This study investigates the effect of various PNS based superplasticizers on the rheological performance and mechanical (compressive strength) performance of a RPC mixture. Six distinctive types of PNS based superplasticizers were used; three of various compositional strengths (high, medium, low range) from a local provider, and three of the same compositional strengths (high, medium, low) from a leading manufacturer. The properties investigated were the individual superplasticizers' viscosity, the concrete workability, determined through a mortar spread test, the concrete viscosity, and the compressive strength of the hardened RPC mixtures measured at 7, 14, and 28 days. Two separate RPC mixtures were prepared, which contained two different water-to-cementitious ratios, which consequently increases the dosage of superplasticizer needed, from 34.8L/m3 to 44.7L/m3. The results show that the name brand high range composition produced the overall highest spread, lowest viscosity, and a highest compressive performance. However, the local provider outperformed the name brand in the mid and low range compositions. Lastly, the rheology assessment also confirmed that the name brand high range, and RPC fabricated with the name brand high range, developed the lowest viscosities.

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 DOI: https://doi.org/10.30564/jbms.v2i1.2731

1. Introduction

As the world's structures increase in height and overall size, so does the necessity for higher performance building materials. Concrete is the most used building material in the world, but conventional concretes are lacking in the necessary performance for the next generation of structures. Higher strength and performance concretes meet this demand, however, not all aspects are currently known and therefore, require more investigation. A particular type of high strength concrete is known as Reactive Powder Concrete (RPC). RPC is a concrete with highly reactive constituents that results in a high strength and highly ductile material. RPC type concretes typically have compressive strengths at or above 130 MPa. RPC mixtures typically consist of only powders that react well with each other to produce high performance properties. These materials typically consist of Portland cement, Silica Fume, Fly Ash, Slag, fine (powdered) aggregate, and fibers. RPCs also typically require the use of admixtures to adjust certain properties. These admixtures are commonly a superplasticizer type, which typically increases the workability of the fresh concrete and helps with high early-age strength. The admixtures also help to provide an increase in compressive and tensile strength as well as other durability properties. The nature of a superplasticizers is to allow for an effective dispersion of cement particles to ensure complete hydration, packing density, and workability within the mixture. RPCs typically have very low water-to-cementitious (w/cm) ratios, which typically results in a very viscous mixture and the possibility of conglomerated un-hydrated cement particles. A superplasticizer will not only help to break up these conglomerations, ensuring all particles are properly hydrated, it will also improve the workability for easier handling and placing.

There are typically three compositional strengths for these superplasticizers, which consist of high, medium, and low range. These three strengths are commonly used to change the viscosity of the fresh concrete. Requirements for these admixtures are outlined by ASTM C494 "Standard Specifications for Admixtures in Concrete" [1]. Common examples of superplasticizers include, Polymelamine Sulfonate, Polynaphthalene Sulfonate (PNS), and (PMS) and Polycarboxylate Ether (PCE) based polymers. These admixtures are all used to deflocculate the cement particles and increase the workability of the fresh concrete mixture [1-5]. The effectiveness of an individual superplasticizer is a result of the chemical structure, main backbone length, composition of functional groups, side chain length, degree of backbone polymerization, and charge density differentiation [4-5].

This study focuses on investigating the impact of different PNS based superplasticizers on the workability and compressive strength of RPC. Six various PNS based superplasticizers were obtained and implemented; three different PNS based superplasticizers (high, medium, and low) from a local manufacturer (PNS-L-high, PNS-L-medium, PNS-L-low), and three PNS-based superplasticizers from a name brand manufacturer, also in a high, medium, and low composition (PNS-N-high, PNS-N-medium, PNS-N-low). The products produced and provided by a local company are understood to produce comparable results to the name brand products. The focus of this study is to determine the effect of various Polynapthalene Sulfonate (PNS) superplasticizers have on the compressive strength and rheological performance of RPC. The workability of the concrete was measured via a mortar spread test. To compare the viscosity properties of the superplasticizer and the RPC mixtures a viscometer was used.

2. Experimental Program

2.1 Materials and Mixture Design

Ordinary Portland Cement (Type I/II) cement was used in all concrete mixtures, which conforms to ASTM C150 Standard Specification for Portland Cement [6]. Powdered silica fume was also used, to help improve particle packing of the mixtures. The very fine particle size of silica fume is known to enhance particle packing and increase the cement reaction to improve strengths in RPC. The only aggregate used in the mixtures was a river sand. The sand was sieved over a #30 sieve and was then washed on a #200 sieve. After washing, the rive sand was then dried in a laboratory oven at 110ºC for 24 hours prior to mixing. Based off of a literature review, two RPC mixtures were designed [7-10] that contained two different w/cm., The two w/cm will elucidate the impact of the amount of superplasticizer used. Table 1 shows the mixture design proportions used for the two mixtures. Table 2 contains information about each superplasticizer used.

Table 1. RPC mixture quantities

Materials	w/cm = 0.20 (kg/m^3)	w/cm = 0.15 (kg/m^3)
Type I/II Cement	880	880
Silica Fume	220	220
River Sand	830	1010
Superplasticizer	34.8 (L/m^3)	44.7 (L/m^3)
Water	220	165

 DOI: https://doi.org/10.30564/jbms.v2i1.2731

Table 2. Superplasticizer Properties

	PNS-L-high (Yellowish Liquid)	PNS-L-med (Yellowish Liquid)	PNS-L-low (Gold/Brownish Liquid)
pH, 25ºC	6.11	6.08	6.19
Density (g/cm^3)	1.11	1.09	1.08
Mass average molecular weight	49,000	50,000	41,000
Side chain density of carboxylic acid groups	1:4	1:3	1:5
Appearance	PNS-N-high (Gold/Brownish Liquid)	PNS-N-med (Gold/Brownish Liquid)	PNS-N-low (Gold/Brownish Liquid)
pH, 25ºC	6.12	6.10	6.14
Density (g/cm^3)	1.15	1.16	1.15
Mass average molecular weight	49,000	47,000	45,000
Side chain density of carboxylic acid groups	1:4	1:3	1:5

Note: *PNS = Polynapthalene Sulfate; **L = Local Provider; ***N = Name Brand

2.2 Sample Preparation

The mixing method was completed based off of experience and a review of the literature [7-10]. The mixing procedures consisted of mixing of all of the constituents was completed for 15 minutes using a pan mixer. The dry constituents were mixed for the first 5 minutes followed by the addition of 75% of the water. After an additional 5 minutes, the desired superplasticizer was added with the remaining 25% of the water, followed by 5 minutes of mixing. In order to ascertain the impact of the three compositional ranges as well as the difference between the various types of superplasticizers one dosage amount was selected despite the compositional range of the three types. Additionally, one specific curing treatment was used for the compression testing samples. The curing treatment was originally developed by Shaheen and Shrive [9] and demonstrated replicable results. First the samples are cured at room temperature 23ºC (73ºF) for the first 24 hours, and after demolding, the specimens were then heat cured in a water bath at 50ºC (122ºF) until 2 days prior to testing. At two days prior to testing, the specimens were removed from the water bath and dry cured at 200ºC (392ºF).

Compressive strength specimens were casted into 50-mm (2-in.) cube molds. All samples were compacted according to the mortar cube compaction method described in ASTM C109 [11] "Compressive Strength of Hydraulic Cement Mortars". Cubes specimens were used to avoid issues with end preparation of cylindrical specimens [11]. After the specimens were properly cured, they were individually tested according to BS 12390-3- 2019 [12]. An average of three samples was tested per individual data point described in the results section.

2.3 Testing Equipment

Testing of the mortar flow (spread) was completed in accordance to ASTM C1437-20 [13], which was completed immediately following mixing of the RPC mixtures. The rotational viscosity was also obtained. Both the superplasticizer was measured as well as the freshly mixed RPC. A Brookfield model DV-II+ rotational viscometer was used for all superplasticizers and the RPC mixtures. Viscosity measurements of the fresh concrete was done in parallel with the flow spread test and casting of the compressive strength cubes.

3. Results

The viscosity of each superplasticizer was recorded at 3 different rates (20, 50 and 100 rpm) shown in Figure 1. The viscosity measurements were recorded in centipoises, cP at three different angular speeds to investigate how the viscosity changes with different speeds (sheer capacity). In addition to the superplasticizer viscosity the spread flow data measured from the fresh RPC mixtures can be seen in Table 3.

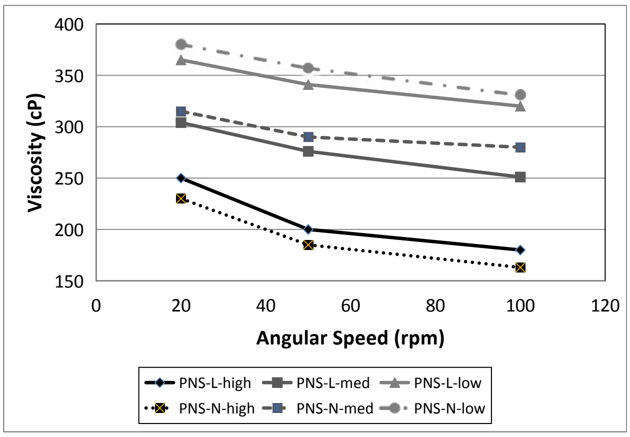

Figure 1. Viscosity measurement of each superplasticizer at individual rotational speeds

Table 3. Spread flow results of the RPC mixtures

Superplasticizer	w/cm = 0.20 (mm)	w/cm = 0.15 (mm)
PNS-L-high	205.9	196.4
PNS-L-med	187.3	175.6
PNS-L-low	169.1	153.3
PNS-N-high	210.6	202.2
PNS-N-med	181.2	169.4
PNS-N-low	163.0	147.1

DOI: https://doi.org/10.30564/jbms.v2i1.2731

Both Figure 1 and Table 3 demonstrate that the viscosity of each superplasticizer dosed in the RPC mixture has an effect on the workability of the mixtures. The results demonstrate that the PNS-N-high produced the lowest viscosity measured, and the RPC mixtures also made with the PNS-N-high resulted in the highest spread. The general trend seen in both the viscosity measurements and spread test is that the high composition superplasticizer produced the lower viscosity and highest spread, followed by the medium range composition, then lastly the low range composition. This result is as expected as the broader the range, the higher the impact on the viscosity and spread at the same dosage level [1-5]. In general, RPC mixtures have a high viscosity and low spread, which results in lower workability and a less pumpable mixture [7-10]. Therefore, a higher spread and lower viscosity is generally preferable, however, this does depend on the application. What can also be seen is that the name brand superplasticizer does not always produce a lower viscosity and higher spread. In fact, the name brand only outperformed the locally provided PNS in the high range category. Based off of these results there seems to be a difference in composition between the different superplasticizers despite the marketed similarity. Both manufactures do not reveal their specific chemical composition due to their proprietary ingredients. Despite this fact, this study still provides beneficial information on the impact of various PNS based superplasticizers on RPC types of concretes. The results also elucidate that despite the increase in superplasticizer dosage between the two w/cm mixtures, the workability (spread flow) still decrease for the 0.15 w/cm ratio concrete.

The outcome of the viscosity measurements of the RPC mixtures produced with the various superplasticizers can be found in Figures 2-3.

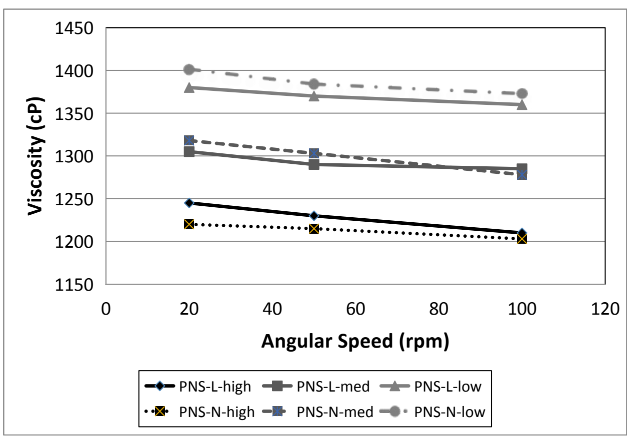

Figure 3. Viscosity measurements of the RPC produced with the six PNS-based superplasticizers at a 0.20 w/cm

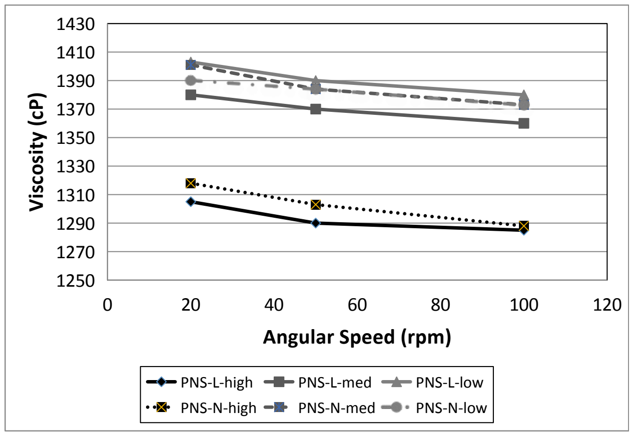

Figure 4. Viscosity measurements of the RPC produced with the six PNS-based superplasticizers at a 0.15 w/cm

The results shown in Figures 3 and 4, ultimately demonstrate that the viscosity of the RPC mixture is considerably higher than that of the pure superplasticizers. Despite this increase, the high results are not as expected for this type of concrete, as these types of concretes traditionally only contain high amounts of powders, which typically results in a viscous mixture. These mixtures also typically contain a high amount of silica fume, which is spherical in nature, and very fine. The particle morphology of this powder will help to improve the workability of these types of concrete, and this is likely the case in the results of this study. It can be seen in Figures 3-4 that the various superplasticizers produce an effect on the workability (measured viscosity) of the RPC mixtures at the three measured rotational speeds, which is expected. A correlation is observed between the viscosity of the of the superplasticizer compositional range and its influence to the RPC mixtures. This correlation can be seeing in Figures 2-4. As with just the viscosity of the superplasticizer, the higher the range of the superplasticizer the higher the impact on the concrete's viscosity. Additionally, there is a correlation between the viscosity of the superplasticizers and the viscosity of the RPC mixtures, such that the lowest measured superplasticizer produced the lowest measured RPC viscosity and similarly with the highest viscosity superplasticizer and the highest RPC viscosity. Hence, the order from lowest to highest of just the superplasticizer liquids are in the same order as the RPC produced with the same superplasticizers, aside from PNS-L-high, which performed with a slightly lower viscosity than its counterpart. This only occurred at the lower w/cm of 0.15 and not in the w/cm of 0.20. The overall correlation is expected as the superplasticizer is creating the desired viscosity within the concrete as per its design due to its inherent properties. The difference in the PNS-L-high versus PNS-N-high is very close to each other, therefore this difference is likely negligible. Also note that at an angular speed of 100, the viscosity of the PNS-L-high and PNS-N-high are essentially the same. The results in Figures 3-4, also reveal that the overall viscosity increases marginally with the lower w/cm. This result is expected as a lower w/cm means less water, and less water tends to have a higher viscosity. This result is still observed despite the additional dosage of superplasticizer used. These results are also similar with the mortar flow test. It can also be seen that the superplasticizer properties seen in Table 2 have no effect on the viscosity of the superplasticizers or the RPC. It is noticed that the main property affecting the viscosity of the RPC mixtures is the viscosity of the superplasticizer itself.

The compressive strength results were obtained in accordance to BS EN 12390-3-2019 [12] which uses 50-mm (2-in.) cubes. The results of this testing can be seen in Figure 4.

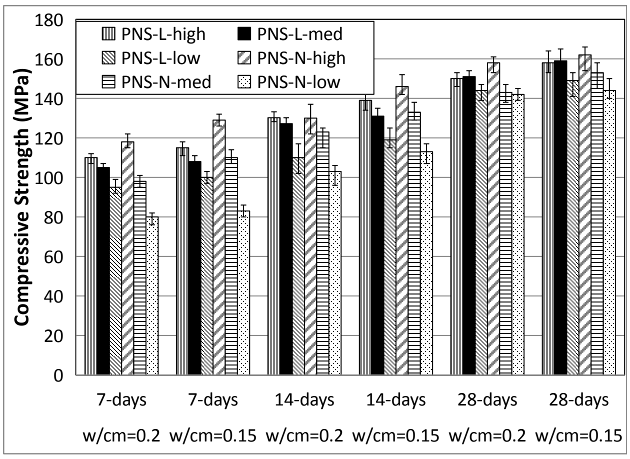

Figure 4. Compressive strength results

The outcome of the compression strength testing showed results that are similar with the viscosity and spread tests discussed previously. These results are as expected based off of the literature. Specifically, the compressive strengths are proportional with curing age, in that they increase with age. Additionally, also as expected, the compressive strengths increase with a decrease in w/cm. The highest strength achieved was 162MPa produced by the 28-day, 0.15 w/cm, PNS-N-high mixture. The lowest compressive strength recorded was the 0.20 w/cm measured at an age of 7-days. This result was from the PNS-N-low with a strength of 80MPa. Although this is a lower strength than expected this strength should be noted as a sufficiently high compressive strength when related to standard concretes. It is also noticed that the PNS-N-high regularly yielded the highest results with the PNS-L-high following. The next highest performing mixtures were the PNS-L-med, PNS-N-med, PNS-L-low and PNS-N-low for the remaining compressive strengths. Therefore, the name brand only outperformed the counterparts in the high range categories. It can also be observed that PNS-N-low always produced the lowest strengths, which also corresponds to the highest superplasticizers' viscosity and also the highest RPC mixture viscosity. It is observed that all of the compressive strength measurements have an inverse relationship to the spread test and viscosity amounts of both the individual superplasticizers and the RPC mixtures. Hence, the superplasticizer and corresponding mixture with the lowest viscosity produced the highest compressive strengths. Therefore, the less workable the mixture the higher the compressive strength. This outcome is expected as the only variable changing is the superplasticizer itself, which only impacts the workability. A lower workability, typically signifies a denser mixture, which results in a higher compressive strength concrete. The workability is a performance measure that relates to the ease of placement and compaction of the material, therefore, a compromise between strength and ease of placement must be made. Based off the results of this study and similar studies in the literature, the impact of a superplasticizer on the workability and compressive strength of a concrete is directly proportional to the viscosity of the superplasticizer itself.

4. Conclusions

This study demonstrated the influence that six different PNS based superplasticizers has on two RPC mixtures. Of the six superplasticizers three were from a leading name brand company and three were provided from a local competing company. One overall type of superplasticizer was used (PNS), with three different compositions of high, medium, and low. The high range superplasticizers overall yielded the best performance, however only the high range from the name brand provider outperformed its counterparts. The outcome from the viscosity testing revealed how each superplasticizer performed at different rotational speeds. This data elucidated the effect that each superplasticizer had on the two RPC mixtures. The results showed that the locally provided superplasticizers in the mid and low range produced lower viscosities, which led to a higher mortar spread of the corresponding RPC mixture, which in turn resulted in a more workable concrete, which ultimately led to higher compressive strengths at all ages versus the name brand counterparts. The lowest viscosity concretes were produced by the low range superplasticizers. The lower workable RPCs also corresponded to lower compressive strengths, which is likely a result of a lower hardened density (not measured) and less hydration of all cementing particles. The findings produced in

DOI: https://doi.org/10.30564/jbms.v2i1.2731

this study demonstrate how various PNS based superplasticizers impact the performance of RPC type concretes.

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ARTICLE

Concrete Mix Design by IS, ACI and BS Methods: A Comparative Analysis

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ARTICLE INFO

Article history
Received: 30 November 2020
Accepted: 9 December 2020
Published Online: 30 March 2021

Keywords:
Concrete
Mix design
Indian standards
ACI code
BS code

ABSTRACT

Concrete is one of the most consumable construction materials on the earth. The concrete constitutes cement, sand, gravel, water and/or additives in definite proportions. The proportions of raw materials of concrete are decided by the concrete mix design. The mix design depends on the various factors. For mix design, most of the countries have their own specifications. In the present study, standard guidelines of India, Britain and America for the concrete mix design have been discussed. The concrete grades of M25, M35 and M45 were designed and compared. Indian Standards were also compared. It was concluded that a new revised version of Indian Standard code has the lowest value of water/cement ratio and highest quantity of cement as compared to other standards.

1. Introduction

Among all the construction materials, concrete is the prime material which is used in the construction of building elements, pavements, tanks, transmission towers etc. The reason of enormous use of concrete from many years is its universal versatility, economy, ease in mould to any shape and good durability. Also, ingredients of concrete are easily available in any part of the country. Concrete is made up of cement as binder, aggregates as inert materials, water and admixtures (optional) in a definite proportion. The proportions of ingredients in concrete mixtures are determined by mix design. Concrete mixes are classified as nominal mix and design mix. Nominal mix is adopted for small scale constructions while design mix concrete is adopted for important or large-scale construction work. Concrete mix design is a technical procedure to select the suitable proportions of ingredients to achieve the required strength or performance to satisfy the job requirements i.e. workability, strength and durability etc. This definite proportion of materials in the concrete mixtures has important role in quality of end product. This proportion of ingredients is expressed ratio wise i.e. 1:3:6 represents 1 part of cement, 3 parts of fine aggregate (FA) and 6 parts of coarse aggregate (CA). The water-cement ratio (w/c) or any additives are expressed separately [1-3].

The purpose of mix proportioning is to obtain the most economic and practical combination of readily available materials; which satisfy the performance of concrete. Basic data required for the mix proportioning are concrete grade, type and content of cement, maximum nominal size of aggregates, maximum water-cement ratio (w/c), slump,

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DOI: https://doi.org/10.30564/jbms.v2i1.2636

exposure conditions, type and properties of aggregates; and admixtures. Mix proportions of concrete depend on the input data required for design as mentioned above. The performance of concrete mixtures is affected by the various factors i.e. cement content, water, aggregates, batching, mixing, compaction and curing techniques. The mix proportioning is accomplished by use of certain empirical relations, which helps to find the best combination of ingredients to achieve the required properties. Mostly, mix design is based on empirical relationships, charts and graphs developed from extensive experimental investigations. Basically, all follow the same principles except some minor variations like various methods in selection of the mix proportions [1]. Some of commonly used mix design methods are as follows:

i) Mix design as per Indian Standard (IS)

ii) British DoE method (BS)

iii) American Concrete Institute method (ACI)

Santhosh and Shivananda [4] studied and compared the mix design of concrete for M15, M30 and M45 by using IS: 10262:2009, ACI and BS method. It was found that w/c for all grades of concrete was more in BS method and less in IS method. ACI method gives better results without superplasticizer as compared to IS code [5]. Mix design of M35 and M40 concrete was done by various standards with rounded aggregates [6].

In the present study, a comparative study of concrete mix design by the various countries standard (IS:10262-2009, IS:10262-2019, BS and ACI method) was conducted [7-10]. The grades of concrete were M25, M35 and M45 for different design parameters. The Indian standards were also compared with or without chemical admixtures. The comparison was made in terms of quantities of ingredients.

2. Methodology

In the concrete mix design, standard grades of concrete M25, M35 and M45 were designed by IS, BS and ACI; and compared.

2.1 Mix Design as Per IS

IS: 10262-2009 presents the guidelines for the design of concrete mix. The second revision i.e. IS: 10262-2019 "Concrete Mix Proportioning-Guidelines" confirms the design of high strength concrete, self-compacting concrete and mass concrete along with standard strength of concrete upto 60MPa. This new code also implemented the new revised code of fine and coarse aggregates. A graph between w/c and 28 days compressive strength has been introduced which depend on type and grade of cement, for the selection of w/c. The w/c has an important role on the compressive strength of concrete mixtures and; selected on the basis of grade of concrete and type of exposure. The steps involved in the mix design of concrete are as follows:

i) Selection of w/c

ii) Selection of free water content

iii) Determination of cement content

iv) Determination of fine and coarse aggregates

2.2 Mix Design as Per ACI

In 1991, American Concrete Institute (ACI) published the guidelines for the mix design of normal, heavy-weight and mass concrete. The absolute volume method of mix design as described by the ACI Standard 211.1 "Recommended Practice for Selecting Proportion for concrete" and design steps is given as below [1]

i) Selection of slump

ii) Selection of maximum aggregates size

iii) Determination of mixing water and air content

iv) Computation of target mean compressive strength

v) Selection of w/c

vi) Determination of cement content, coarse aggregate and fine aggregate

vii) Adjustments for aggregates moisture

2.3 BS DoE Method

British DoE method was first published in 1975 and was revised in 1988. It is a general method developed by the Department of Environment that can be applied to produce designed concrete, using cement and aggregates which conform to the relevant British Standards. The mixes are specified by the mass of the different materials contained in a cubic metre. The basic mix design approach is same and based on the characteristics value approach for strength, target mean for slump and air, the minimum target mean for cement content and maximum target mean for w/c. Design steps for the concrete mix design are as follows [1]:

i) Selection of w/c

ii) Determination of free water content followed by cement content

iii) Computation of total volume of aggregates followed by determination of fine and coarse aggregate content

iv) Adjustments for aggregates moisture

v) Determination of final proportions

The properties of concrete mixtures depend on the quality of the raw materials i.e. cement, aggregates and w/c used. The parameters which were considered during the

 DOI: https://doi.org/10.30564/jbms.v2i1.2636

mix design were given in Table 1.

Table 1. Parameters considered in mix design

Sr. No.	Parameters	Value	
1	Characteristics compressive strength	25MPa, 35MPa, 45 MPa	
2	Cement	OPC 43	
3	Specific gravity	Cement	3.15
		Sand	2.65
		Coarse aggregates	2.74
4	Nominal maximum size of aggregates	20 mm	
5	Nature of aggregates	Natural crushed aggregates	
6	Workability	50-100mm	
7	Admixtures	0%-2% @1%	
8	Oven dry rodded bulk density	1600 kg/m^3	

3. Results and Discussion

The mix design for concrete of grades M25, M35 and M45 was carried out and, compared with IS: 10262-2009 and IS: 10262-2019. During mix design, the design parameters were same.The water content of a particular grade for both Indian standards was kept same. Similar for 28 days compressive strength of concrete was designed by ACI and BS method. The mix proportions i.e. ratio of ingredients in the concrete mixtures has been given in Table 2 and the quantities of various ingredients have been given in Table 3. Table 2 showed the mix proportions i.e. ingredients by parts for all grade of concrete by different standards. Cement part is taken as unity and aggregates and water parts accordingly.

For M25 concrete, cement content was high and aggregates for the same content of water for mix design by IS: 10262:2019. From the graph of compressive strength and w/c ratio, w/c ratio chosen was lower than the taken from experience as in case of IS: 10262:2009.In the absence of chemical admixtures or ordinary concrete, w/c was little higher and cement content was low in case of ACI method of mix design. IS: 10262:2019 and BS method have similar content of ingredients as depicted in Table 3.

For M35 concrete, addition of superplasticizer (1%) in the concrete mixture reduced the content of water and increased the cement content as shown in Table 3. In absence of superplasticizer, new IS code recommends high content of cement with a lower w/c ratio. According to old IS method of mix design, the cement content found to be lowest among all the mix design methods. While, for the same grade of concrete, cement and water content for BS method was higher than new IS methods.

For 45 MPa concrete, having 2% superplasticizer w/c for new IS code was found lower than that of old IS code in respect of 28 days compressive strength; while, corresponding cement content was found higher as found in. Moreover, the cement content and water content were higher for both the standard in case of without superplasticizer. For high strength concrete with lowest w/c 0.28 had highest cement content of around 704 kg/m^3 according to new IS code while, for similar grade old IS code had lowest quantity of cement and highest w/c.

Apart from the proportions and quantity of materials in concrete mixtures, it is well known fact that the production of concrete contributes to greenhouse gases emission and is not eco-friendly end product. Also, cost of cement is high. On the other side, the mining for the aggregates has bad impact on the environment. Practitioners should focus on the environment friendly materials to save the natural resources. To conserve the environment, the locally available waste materials should be introduced in the construction industries as substitution to cement and aggregates.

Table 2. Mix proportions of grades of concrete by IS, ACI and BS methods

Chemical admixture

Sr. No.	Characteristic strength (MPa)	Standards	Proportions (Cement : FA : CA : w/c : SP)
1.	25	IS (Old)	1 : 2.32 : 4.09 : 0.46 : 0.01
2.	IS (New)	1 : 2.22 : 3.95 : 0.44 : 0.01	
3.	35	IS (Old)	1 : 2.39 : 3.27 : 0.42 : 0.01
4.	IS (New)	1 : 1.48 : 2.87 : 0.34 : 0.01	
5.	45	IS (Old)	1 : 2.0 : 2.82 : 0.38 : 0.02
6.	IS (New)	1 : 1.1 : 2.21 : 0.28 : 0.02	

Without chemical admixture

Sr. No.	Grade	Standard	Proportion (Cement: FA: CA: w/c)
1.	25	IS (Old)	1 : 1.60 : 2.18 : 0.45
2.		IS (New)	1 : 1.54 : 2.74 : 0.44
3.		ACI	1 : 1.89 : 2.55 : 0.47
4.		BS	1 : 1.60 : 2.73 : 0.45
5.	35	IS (Old)	1 : 1.63 : 2.23 : 0.42
6.		IS (New)	1 : 1.01 : 1.96 : 0.34
7.		ACI	1 : 1.39 : 2.15 : 0.43
8.		BS	1 : 1.26 : 1.54 : 0.39
9.	45	IS (Old)	1 : 1.36 : 1.92 : 0.38
10.		IS (New)	1 : 0.72 : 1.47 : 0.28
11.		ACI	1 : 0.89 : 1.50 : 0.3
12		BS	1 : 1.01 : 1.40 : 0.35

DOI: https://doi.org/10.30564/jbms.v2i1.2636

Table 3. Quantities of materials of concrete mixtures

Sr. No.	Grade	Standard	Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)	w/c	SP (%)
1	M25	IS (Old)	318	739	1302	143	3.18	0.45	1
		IS (New)	325	723	1283	143	3.25	0.44	1
2		IS (Old)	413	660	1162	186	0	0.45	0
		IS (New)	423	653	1160	186	0	0.44	0
3		ACI	404	763	1024	190	0	0.47	0
4		BS	422	676	1152	190	0	0.45	0
5	M35	IS (Old)	352	840	1151	148	3.52	0.42	1
		IS (New)	436	646	1251	148	4.36	0.34	1
6		IS (Old)	457	744	1020	192	0	0.42	0
		IS (New)	564	571	1106	192	0	0.34	0
7		ACI	477	662	1024	205	0	0.43	0
8		BS	577	728	890	225	0	0.39	0
9	M45	IS (Old)	400	802	1127	152	8	0.38	2
		IS (New)	543	588	1201	152	5.43	0.28	2
10		IS (Old)	518	707	993	197	0	0.38	0
		IS (New)	704	507	1035	197	0	0.28	0
11		ACI	683	610	1024	205	0	0.30	0
12		BS	643	652	900	225	0	0.35	0

4. Conclusions

The concrete mix design adopted in various countries has been done and compared. As a thumb rule, lower will be the w/c, higher will be the cement content. New IS code suggests higher cement content and lower w/c than old IS code. For good strength and durability properties of concrete, lower w/c is the main requirement. The difference may be justified by the fact that new IS code introduced a graph between w/c and compressive strength while, old IS code dictates that the w/c may opt from experience of the practitioner/engineer. The quantity of cement and w/c ratio were found close in case of BS and IS codes for 25MPa and 35MPa characteristics strength while, IS and ACI codes recommend same input design parameters for 45MPa strength characteristics concrete mix. The new IS code advocates higher content of cement that leads to a higher cost of end product and huge carbon dioxide emission. For sustainable construction, industrial waste materials can be used as partial replacement of cement or aggregates.

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ISSN 2630-5216
9 772630 521200 01
Price: S$30.00