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[114].

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]. RHA 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); during cement hydration[16].

Table 1. Soil improvement by different materials

| Author(s) | Additives | Results |
|-----------|-----------|---------|
| Cucci et al., 2008[26] | Wet olive pomace | The use of wet olive pomace improved the soil fertility and nutrient content. The wet pomace lowered the pH of soil. 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 up to 1.5% increased the UCS value beyond that it decreased. Increase in FT cycles decreased the UCS values. Mushroom waste improved the soil properties. Soil with MD showed better performance. MD at 5% attained maximum UCS value. Differential free swell (DFS) and MDD decreased while, pH, UCS and soaked CBR values increased with the use of additives. 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.
| Jafari and Esmashaari, 2012[19] | Nylon Fibre (0%, 0.5%, 1% and 1.5%) and Lime (0%, 4% and 8%) | The inclusion of GGBFS and CW increased the UCS. CW alone produced insignificant improvement and GGBFS alone increased the UCS significantly. RD increased the strength of soil in grouting. RD (15%) + PC (85%) helped to attain maximum UCS value.
| Guo et al., 2013[10] | Mushroom waste | The use of wet olive pomace improved the soil fertility and nutrient content. The wet pomace lowered the pH of soil. 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 up to 1.5% increased the UCS value beyond that it decreased. Increase in FT cycles decreased the UCS values. Mushroom waste improved the soil properties. Soil with MD showed better performance. MD at 5% attained maximum UCS value. Differential free swell (DFS) and MDD decreased while, pH, UCS and soaked CBR values increased with the use of additives. 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.

| Sharma and Hymavathi, 2016[20] | Fly ash, C&D, waste lime | The use of wet olive pomace improved the soil fertility and nutrient content. The wet pomace lowered the pH of soil. 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 up to 1.5% increased the UCS value beyond that it decreased. Increase in FT cycles decreased the UCS values. Mushroom waste improved the soil properties. Soil with MD showed better performance. MD at 5% attained maximum UCS value. Differential free swell (DFS) and MDD decreased while, pH, UCS and soaked CBR values increased with the use of additives. 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.
| Soltani Jighbeh, 2016[14] | Plastic waste (0%, 0.5%, 1%, 1.5% and 3%) | The use of wet olive pomace improved the soil fertility and nutrient content. The wet pomace lowered the pH of soil. 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 up to 1.5% increased the UCS value beyond that it decreased. Increase in FT cycles decreased the UCS values. Mushroom waste improved the soil properties. Soil with MD showed better performance. MD at 5% attained maximum UCS value. Differential free swell (DFS) and MDD decreased while, pH, UCS and soaked CBR values increased with the use of additives. 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[20] | Ground granulated blast furnace slag (GGBFS) and recycled construction waste (CW) in Bentonite clay Red mud (RD) at 0.5% and 100%; and Portland cement (PC) at0% and 75100%@5% in soil grouting | The inclusion of GGBFS and CW increased the UCS. CW alone produced insignificant improvement and GGBFS alone increased the UCS significantly. RD increased the strength of soil in grouting. RD (15%) + PC (85%) helped to attain maximum UCS value.
| Çelik, 2016[20] | RHA (0%, 2%, 4%, 6% and 8%) and ordinary Portland cement (OPC) (2%, 4%, 6% and 8%) Natural fibre (Jute fibre, coir fibre and sabai grass) at 1%, 1.5%, 2% and 2.5% | The inclusion of GGBFS and CW increased the UCS. CW alone produced insignificant improvement and GGBFS alone increased the UCS significantly. 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%) Natural fibre (Jute fibre, coir fibre and sabai grass) at 1%, 1.5%, 2% and 2.5% | The inclusion of GGBFS and CW increased the UCS. CW alone produced insignificant improvement and GGBFS alone increased the UCS significantly. RD increased the strength of soil in grouting. RD (15%) + PC (85%) helped to attain maximum UCS value.
| Rahgozari et al., 2017[18] | RHA (0%, 2%, 4%, 6% and 8%) and ordinary Portland cement (OPC) (2%, 4%, 6% and 8%) Natural fibre (Jute fibre, coir fibre and sabai grass) at 1%, 1.5%, 2% and 2.5% | The inclusion of GGBFS and CW increased the UCS. CW alone produced insignificant improvement and GGBFS alone increased the UCS significantly. RD increased the strength of soil in grouting. RD (15%) + PC (85%) helped to attain maximum UCS value. Increase in RHA content increased OMC and decreased MDD. RHA and OPC improved the UCS and CBR values accordingly. Increase in fibre content decreased the MDD and increased OMC. Increase in fibre up to 2% increased the CBR and UCS.

The use of wet olive pomace improved the soil fertility and nutrient content. The wet pomace lowered the pH of soil. 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 up to 1.5% increased the UCS value beyond that it decreased. Increase in FT cycles decreased the UCS values. Mushroom waste improved the soil properties. Soil with MD showed better performance. MD at 5% attained maximum UCS value. Differential free swell (DFS) and MDD decreased while, pH, UCS and soaked CBR values increased with the use of additives. 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.
### Results - Additives

| Author(s)                  | Additives                                      | Results                                                                                                                                 |
|---------------------------|------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Pathania and Sohi, 2017   | 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 Bibel, 2018      | Marble powder (MP), Marble dust (MD)           | The use of plastic strip (0.4%) as reinforcement increased maximum dry unit weight (MDU), shear strength and CBR.                   |
| Peddadiah et al., 2018    | Plastic bottle strip (0.2%, 0.4%, 0.6% and 0.8%) in silty sand | Addition of lime and sludge increased the strength with curing time. Steel sludge was found better in improving the strength than copper sludge. |
| Noorzad and Motavallian, 2018 | Lime (4%, 6%, 8%, 19% and 12%), steel and copper sludge | Chemical waste and lime stabiliser (4%, 6%, 8%, 10% and 12% each) increased the Atterberg limits.                               |
| Khazaai Hossein Moayedi, 2019 | Chemical waste and lime stabiliser (4%, 6%, 8%, 10% and 12% each) | Addition of chemical waste and lime improved the stressstrain and volumetric behaviour. Increase in C&D waste increased the pH. |
| Sharma and Sharma, 2019   | Crushed C&D waste (4%, 8%, 12%, 16%, 20%, 24% and 28%) | Addition of waste glass increased PL and shrinkage limit. Waste glass up to 9% increased MDD and decreased OMC afterwards open test was observed. |
| Paribar et al., 2019       | Soda lime glass (0%, 3%, 6%, 9% and 12%) and Microfine slag (MFS) | Additive of waste glass increased PL and shrinkage limit. Waste glass up to 9% increased MDD and decreased OMC afterwards open test was observed. |
| Bikak et al., 2019         | Lime, waste material, sodium silicate          | Plastic properties were found to be improved with the inclusion of air entrainer. Strength properties of Himalayan soil improved with the addition of ESP, PPF and NaCl under both normal and harsh conditions. The mass loss of soil under FT cycles was within permissible limits. |
| Kumar et al., 2019         | ESP, PPF and NaCl                              | Both additives reduced LL, MDD and swelling characteristics and increased UCS.                                                        |
| Kumar et al., 2019         | ESP, PPF and NaCl                              | 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. |
| Kumar et al., 2019         | ESP, PPF and NaCl                              | Waste tire rubber fibre (0%, 0.5%, 1% and 2%) and cement (5%, 7.5% and 10%) in bentonite clay soil                                  |
| Bekhti et al., 2019        | 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 | Both additives reduced LL, MDD and swelling characteristics and increased UCS.                                                        |
| Choobiastani et al., 2019  | Natural fibres Coconut leaflet (1%, 2% and 3%) | Shear strength ratio of reinforced soil decreased with increase in confining pressure.                                            |
| Liang et al., 2020         | 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      | Electronic (e) waste at 3%, 6%, 9% and 12%    | The swelling potential of clay sample consists nanosilica alone and nanosilica + EAF slag was reduced.                               |
| Shahsavani et al., 2020    | Nanosilica and EAF slag in expansive clayey soil | The addition of lime and sludge increased the strength with curing time.                                                            |
| Sharma and Sharma, 2020    | RHA and C&D waste with or without lime in clayey soil | Upto 5% MP, value of q, and E, increased afterwards it reduced.                                                                      |
| Deboucha et al., 2020      | 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               | 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 Mahmudullah, 2020 | 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        | 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. |

CBR value decreased beyond 10% CW. CW+OPC increased the bearing capacity due to hydration reaction of cement and lime content [23]. 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.
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 \[19\]. Up to 5% MP, value of UCS and E_s 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. Incororporated waste enhanced the freeze/thaw 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 \[11\]. 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 \[12\]. 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 \[10\].

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 silt 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 waterabsorption capacity. 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-
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 \cite{17}. Shear strength ratio of reinforced soil decreased with increase in confining pressure. The soil fibre interaction exhibits bulging behaviour and found to be good additive in enhancing the engineering properties \cite{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 \cite{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 \cite{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 \cite{14, 27, 28}.

![Figure 2. Variation in plastic properties at various percentages of ESP, PPF and NaCl with air entrainer](image)

![Figure 3. Variation in UCS values after various FT cycles](image)

![Figure 4. Variation in mass loss after various FT cycles](image)

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

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