Review Article

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Utilizing Sludges from Tanneries, Water Treatment Plants and Textile Industries in Cement, Concrete and Brick Production: A Review

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ABSTRACT

The review discusses the use of industrial sludges from tanneries, water treatment plants, and textile companies to make cement, concrete, and bricks. It emphasizes the potential of this methodology to deal with industrial sludge disposal difficulties and contribute to eco-friendly industrialization by discovering novel reuse ways for these by-products.

Keywords: Tannery sludge; Water treatment plant sludge; Textile sludge; Bricks; Concrete; Cement.

1. INTRODUCTION

This review paper outlines the challenge of managing the ever-increasing quantity of industrial sludge generated by the growth of industrialization. Emphasizing the environmental impact, the text argues for reducing sludge production and finding compatible reuse options over disposal methods (Spinosa *et al.* 2011). Researchers are encouraged to explore new applications for industrial sludges, particularly in the construction industry, which traditionally relies on natural resources and contributes to their depletion (Spinosa *et al.* 2011). The first reported study in this domain, from 2001, demonstrated the reuse of petroleum industry sludge in making bituminous paints, marking a step towards sustainable industrial waste management (Kuriakose *et al.* 2001). The review specifically focuses on the possibilities of using sludges from tannery, water treatment, and textile industries in producing key construction materials: cement, concrete, and bricks. These industries produce sludges that are typically hazardous. For example, tannery sludge contains high levels of trivalent chromium, which can transform into the more toxic hexavalent form (Payel *et al.* 2020). Textile sludge, resultant from the use of chemicals in production, and water treatment sludge, rich in aluminum, also pose environmental challenges (Shindhal *et al.* 2021).

The manufacturing processes of construction materials like cement and bricks are both energy-intensive and environmentally taxing, releasing significant amounts of greenhouse gases (Hertwich, 2021). The review suggests that substituting some of the conventional raw materials with these industrial sludges could create "green" building materials, offering a dual benefit: disposal of waste and a reduced environmental footprint of material production.

The paper further elaborates that concrete, following cement and bricks, as a predominant building material due to its qualities such as durability, safety, and affordability. However, just like cement and bricks, concrete production also leads to depletion of natural resources (Ramasubramani *et al.* 2021). Incorporating industrial sludge into concrete formulation is posited as a practical approach to resource conservation while sustaining industry demand (De Carvalho Gomes *et al.* 2019).

This review paper discusses the potential of repurposing industrial sludge in the construction industry. It underscores the need for innovative, sustainable practices as a response to the environmental challenges posed by both sludge disposal and material manufacturing processes.

2. LITERATURE REVIEW

The studies on the repurposing of sludges from the textile, water treatment, and tannery sectors for building material manufacturing are examined in this section. It talks about how these sludges, which are typically regarded as waste, can actually be useful secondary raw resources with advantages for the environment and the economy. The properties of tannery sludge are explored, along with ways to stabilize and incorporate it into materials such as cement and bricks (Swarnalatha *et al.* 2006). The chromium level of sludge makes it potentially dangerous, thus handling and treatment should be done carefully before use (Swarnalatha *et al.* 2006). When applied in moderation,

tannery sludge has been shown in several tests to improve the qualities of building materials (Swarnalatha *et al.* 2006).

The review explores the composition of sludge from water treatment plants, which is similar to clay and has potential benefits for the brick industry. When applied properly, the sludge can enhance compressive strength and other characteristics (Kacprzak *et al.* 2017). Tables summarizing research on water treatment plant sludge in the cement and brick industries are included in the publication. They show the ideal sludge content and the resulting material strengths. The production of textile sludge from the textile industry's effluent treatment process is discussed, as well as its potential to pollute the environment. In spite of this, the evaluation indicates that textile waste can be efficiently repurposed in the production of construction materials, but it offers less particular study details or findings than it does for tannery and water treatment sludges. Overall, the analysis of the literature highlights how employing these industrial sludges in place of conventional raw materials in building not only provides a solution to the problem of disposing of waste, but also helps to produce more environmentally friendly and sustainable building materials. According to the publication, additional research and development in this field could improve the processes for combining industrial sludge with building materials, boosting sustainability and advancing environmentally friendly industrial practices of the sectors.

3. UTILIZATION OF SLUDGES IN VARIOUS INDUSTRIES

3.1. Tannery Sludge in Concrete Industry

Research has examined the use of tannery sludge in concrete mixtures as a partial substitute for sand, and the results indicate that modest amounts of this material can be used without significantly altering the concrete's structural qualities. The results indicate that recycling a hazardous waste product that would otherwise need to be disposed of carefully, such utilisation can improve some concrete qualities and support a more ecologically conscious and sustainable economy. The results of many investigations on the addition of tannery sludge to concrete is compiled in Table 1. A distinct study is represented by each row in the table:

- Concrete mixtures containing more than 15% tannery sludge showed a decrease in mechanical characteristics.
- Reddy *et al.* (2016) came to the conclusion that adding sludge might result in the creation of lightweight concrete.
- By mixing in sludge along with an alkali activator solution, Chen *et al.* (2023) improved the split tensile strength of concrete.

Altogether, the table shows that although tannery sludge can be used in the production of concrete, the amount of sludge should be carefully balanced to maintain mechanical qualities and guarantee environmental safety. Changes such as adding alkali activators can also amplify particular strengths.

Table 1. Utilization of tannery sludge in concrete industry

Materials Used	Sludge Content Used	Max. Compressive Strength Achieved in the Study	Ref.
Tannery sludge, cement, coarse aggregate, sand, water	10%	43.64 MPa	(Reddy *et al.* 2016)
Fly ash, cement, coarse aggregate, fine aggregate, tannery sludge, water, alkali activator solution	9%	26.47 MPa	(Chen *et al.* 2023)

3.2. Tannery Sludge in Brick Industry

According to the studies, adding tannery waste may affect the compressive strength of the bricks as well as save energy during the brick burning process because the organic composition of the sludge acts as a fuel source. To guarantee that the finished product stays within environmental safety regulations, the amount of sludge injected must be carefully controlled. This is especially important when it comes to the leaching of chromium, a hazardous component of tannery sludge. While a certain amount of sludge might enhance the sustainability and brick features, too much of it could pose a risk to the environment.

Table 2. Utilization of tannery sludge in brick industry

Materials Used	Sludge Content Used	Max. Compressive Strength Achieved in the Study	Ref.
Tannery sludge, clay, water	10%	16.3 MPa	(Juel *et al.* 2017)
Tannery sludge, fly ash, GGBS, lime, water	20%	8.81 MPa	(Jothilingam *et al.* 2023)

The studies on the use of tannery sludge in brick manufacturing are summarized in Table 2. It includes information on the materials used, the sludge content, replacement materials, compressive strengths attained, and other noteworthy findings like energy savings, changes in elastic modulus, and levels of chromium leaching.

- 10% tannery sludge was combined with clay in the Juel *et al.* (2017) study, producing bricks with a 16.3 MPa compressive strength and using less energy to fire.

- By adding fly ash, GGBS, lime, and water to a 20% tannery sludge mix, Jothilingam *et al.* (2023) were able to achieve a lower compressive strength of 8.81 MPa. Elastic modulus, pore density, and energy savings were probably also examined in this study.

- By combining sand, clay, and a 2.50% sludge content were able to produce bricks with a significantly higher compressive strength of 35 MPa. But according to one study, chromium leaching may become an issue if tannery sludge made up more than 2.5% of the brick.

The inconsistent results seen in these investigations highlight the necessity of carefully evaluating sludge proportions in order to maximize brick strength and environmental safety. Every study sheds light on the difficulties associated with utilizing tannery sludge in building materials, highlighting potential advantages like energy savings and improved structural qualities while also raising concerns about potential negative effects on the environment like chromium leaching.

3.3. Tannery Sludge in Cement Industry

Research studies discovered that it is possible to add specific percentages of tannery sludge to cement without materially altering the cement's characteristics or functionality. Excessive amounts, however, can interfere with the hydration process and perhaps increase chromium leaching, which would be bad for the environment. Tannery sludge must be carefully considered and proportioned for maximum structural soundness and environmental safety.

Table 3. Utilization of tannery sludge in cement industry

Materials Used	Sludge Content Used	Max. Compressive Strength Achieved in the Study	Ref.
Cement, tannery sludge, water	0.7%	48 MPa	(Shen *et al.* 2017)
Cement, superplasticizer, tannery sludge and water	6%	43.2 MPa	(Malaiškienė *et al.* 2019)
Cement, tannery sludge, water	10%	21.5MPa	(Pinto *et al.* 2010)

Three research looking into the use of tannery sludge in cement manufacture are summarised in Table 3:

- In their investigation, Shen *et al.* (2017) used sludge contents ranging from 0% to 7.0%. They discovered that the addition of sludge produced a maximum compressive strength of 48 MPa without adversely affecting the characteristics of cement clinkers.

- With a 6% sludge concentration, Malaiškienė *et al.* (2019) demonstrated that tannery sludge may be added without impairing compliance with 2003/33/EC criteria for chromium leaching, resulting in a compressive strength of 43.2 MPa.

- With a larger level of tannery waste, Pinto *et al.* (2010) noted a slowdown in the cement's hydration process and increased the sludge content to 10%, resulting in a compressive strength of 21.5 MPa.

All of the studies point to the need to carefully calibrate the percentage of tannery sludge in cement production in order to maintain the mechanical properties of the final product and adhere to environmental regulations, especially with regard to chromium content and leaching.

3.4. Water Treatment Plant sludge in Concrete Industry

Several studies tested sludge as a possible partial substitute for conventional concrete materials. The suitability of water treatment sludge for use in concrete mixtures depends on its inherent properties and the proportion in which it is incorporated. Research frequently indicates that there may be advantages, such as resource and waste reduction, without materially lowering the concrete's quality. To guarantee quality and safety standards in the manufacturing of concrete, however, rigorous sludge content optimization is required, just like with any non-conventional material.

Table 4 compares three research that looked into the production of different building materials using sludge from water treatment plants:

- In a 2020 study, Ruben *et al.* (2020) replaced fine aggregate in mortars with 15% water treatment plant sludge, resulting in a compressive strength of 26.4 MPa and an increase in split tensile strength.

- 10% sludge content was utilised in place of fine aggregate in Kaosol (2010) study, which focused on the substitution's financial advantages and resulted in a lower compressive strength of 8.32 MPa.

- Gheller *et al.* (2022) found that water absorption was inversely correlated with compressive strength in 2022 after partially replacing fine aggregate with 2.50% sludge. This resulted in a compressive strength of 10.8 MPa.

Table 4. Utilization of water treatment plant sludge in concrete industry

Materials Used	Sludge Content Used	Max. Compressive Strength Achieved in the Study	Ref.
Water treatment plant sludge, cement, fine aggregate and coarse aggregate, water	15%	26.4 MPa	(Ruben *et al.* 2020)
Water treatment plant sludge, sand, crushed stone dust, cement and water	10%	8.32 MPa	(Kaosol, 2010)
Cement, gravel, sand, water, water treatment plant sludge	2.5%	10.8 MPa	(Gheller *et al.* 2022)
Water treatment plant sludge, un hydrated lime stone, cement, silica fume, sodium silicate solution, coarse aggregate and water	10%	32.38 MPa	(Sofy *et al.* 2023)

Table 4 illustrates how the use of sludge from water treatment plants can affect several mechanical qualities, including compressive and tensile strength, as well as other aspects like water absorption and economic benefits. According to each study, there is a good chance that sludge can be used in place of some building materials, which might save costs and promote more environmentally friendly production methods.

3.5. Water Treatment Plant sludge in Brick Industry

- Better water absorption: Bricks made with 10–20% sludge content has water absorption values that indicate first-class brick quality, whereas bricks made with 30% sludge content are considered second-class.
- The importance of sludge content and burning temperature: The amount of sludge in a brick and the temperature at which it burns affect its compressive strength. Depending on the ideal temperature and composition, the bricks can be classified as first-, second-, or third-class goods.
- Use of sludge with other materials: Research shows that the density and compressive strength of bricks can be impacted by mixing water treatment plant sludge with untreated rice husk ash and quarry dust.
- Impact on brick density and strength: Sludge can significantly reduce brick density and cause differences in compressive strength when combined with certain additives.
- Benefits of the chemical composition: The construction of bricks can profit from the chemical composition of water treatment plant sludge, which is similar to that of clay.

This section will give an overview of the studies conducted on the viability, consequences, and possible economic and environmental advantages of using sludge from water treatment plants in the construction of bricks. It would probably go into the factors that affect the quality of the bricks created, like the composition of the sludge, content percentages, and processing temperatures.

Table 5. Utilization of water treatment plant sludge in brick industry

Materials Used	Sludge Content Used	Max. Compressive Strength Achieved in the Study	Ref.
Water treatment plant sludge, burnt clay brick waste, water	25%	27.4 MPa	(Erdogmus *et al.* 2021)
Water treatment plant sludge, clay, water	20%	0.223 MPa	(Ahmadi *et al.* 2023)
Water treatment plant sludge, quarry dust, cement, untreated rice husk ash, water	15%	1.5 MPa	(Tharshika *et al.* 2019)

Table 5 summarizes several studies on the use of sludge from water treatment plants to make bricks:

- Throughout the studies, a variety of conventional and unconventional material combinations were employed, such as fly ash or agricultural wastes in addition to clay, cement, and sludge.
- Between the trials, there was a considerable variation in the percentage of sludge used in the bricks. The research experimented with substituting sludge for a few of the common materials used in brick construction.
- A wide range of values was seen in the compressive strength, suggesting varying degrees of success in integrating sludge without sacrificing structural integrity.
- The effects on brick qualities including flexibility and water absorption, as well as the requirement for higher sintering temperatures with larger sludge levels, were other observations made in the studies. Additionally, observations were made on the limits of sludge content in terms of preserving sufficient compressive strength.

This table shows that although employing sludge from water treatment plants as a component in brick production is a possibility, it necessitates carefully balancing elements to guarantee that the final bricks fulfil required criteria.

3.6. Water Treatment Plant sludge in Cement Industry

The studies conducted in the utilization of water treatment plant sludge in the cement industry focuses on the effects of partially substituting conventional materials in cement compositions with sludge from water treatment plants, the impact on the cement's physical and chemical characteristics, such as workability, setting time, and compressive strength and the environmental consequences, including resource use and waste reduction, while also taking adherence to the most recent environmental laws and guidelines into account.

Table 6. Utilization of water treatment plant sludge in cement industry

Materials used	Sludge content used	Max. Compressive Strength achieved in the study	Ref.
Water treatment plant sludge, cement, water	7%	47.8 MPa	(Chen *et al.* 2010)
Water treatment plant sludge, cement, water	10%	46 MPa	(Duan *et al.* 2020)
Water treatment plant sludge, cement, water	10%	29 MPa	(He *et al.* 2021)

Three studies looked at using water treatment plant sludge in conjunction with cement and water for construction purposes; the results are summarized in Table 6.

- Chen *et al*. (2010): Utilized 7% of the total sludge and found that compressive strength of maximum of 47.8 MPa was attained in this regard. It was observed that the XRD pattern of the cement clinkers containing sludge was comparable to that of regular cement, indicating the possibility of incorporating sludges into cement without appreciably changing its basic characteristics.

- Duan *et al.* (2020) study: Ten percent of the muck was included and the compressive strength was recorded as 46 MPa. They found that relationship between the sludge content and the capillary absorption of cement mortars, indicating that the sludge concentration may have an effect on the porosity and absorption properties of the cement mortar.

- Research by He *et al.* (2021) proved that ten percent of sludge was also used. In comparison to the other investigations, a reduced compressive strength of only 29 MPa was observed. Their findings revealed that the construction material's strength metrics improved with longer curing times, highlighting the significance of the curing process in enhancing strength when sludge is included in the mixture.

These experiments demonstrate that sludge from water treatment plants can be mixed with building supplies and even used in place of some cement. According to the results, sludge incorporation can produce compressive strengths that are on par with conventional materials up to a certain point. Critical observations that further contribute to a more comprehensive understanding of the effective application of sludge in the construction industry include additional points like the chemical structure's similarity to conventional cement, the impact on capillary absorption, and the advantages of extended curing time.

3.7. Textile Sludge in Concrete Industry

When it comes to handling and disposing of it, textile sludge, a leftover from plant and animal materials remaining after a secondary biological treatment in the textile industry, is a major pollution source. Researchers are looking for ways to handle sludge effectively and safely for the environment by repurposing it in various sectors.

The research on evaluating the viability of using textile waste as a building material by adding it into concrete compositions is summarized in Table 7.

- Beg *et al.* (2022) discovered that adding textile sludge to concrete in place of 10% cement produced a moderate compressive strength of 16.8 MPa. Nevertheless, this modification resulted in increased water absorption, which might have an impact on the concrete's durability and density.

- In a similar experiment, Kasaw *et al.* (2021) achieved a much greater compressive strength of 42 MPa by substituting 10% of the cement with sludge. An increase in the absorption of water was also noted by the study.

- Patil *et al.* (2022), decided to add only 5% sludge to their M30 grade concrete mix instead of cement, and they were able to reach a significant 31 MPa compressive strength, indicating that a concrete with less sludge content can still be strong. They also came to the conclusion that sludge replacement at a maximum of 15% could be the best option in place of cement.

- By replacing a greater percentage (35%) of the fine aggregate with sludge, Harpreet Kaur *et al.* (2017) were able to reach a compressive strength of 23.55 MPa. According to their research, using more than 35% sludge could cause bonding problems that could affect structural performance and integrity. In a somewhat different strategy used fly ash along with sludge to replace 32% of the fine aggregate. They observed that workability– the degree of ease of working with concrete– decreased as sludge content increased and achieved a lower compressive strength of 20.22 MPa.

Table 7. Utilization of textile sludge in concrete industry

Materials used	Sludge content used	Max. Compressive Strength achieved in the study	Ref.
Cement, textile sludge, fine aggregate, water	10%	16.8 MPa	(Beg *et al.* 2022)
Cement, textile sludge, fine aggregate, coarse aggregate water	10%	42 MPa	(Kasaw *et al.* 2021)
Cement, textile sludge, fine aggregate, coarse aggregate water – for M30	5%	31 MPa	(Patil *et al.* 2022)
Cement, textile sludge, fine aggregate, coarse aggregate, plasticizer, water	35%	23.55 MPa	(Harpreet Kaur et al., *et al.* 2017)

The right amount of textile sludge to use in place of cement or fine aggregate varies depending on the study. While adding sludge in place of some standard components might preserve or even increase the strength of the concrete, adding a lot of sludge can often result in reduced strength and workability as well as potential problems with water absorption. These results emphasize the need for a careful balance when adding different components to concrete in order to preserve or improve its qualities.

3.8. Textile Sludge in Brick Industry

Research has looked into the consequences of substituting different amounts of textile sludge for conventional brick materials and the qualities that result. Table 8 details the effects of using textile sludge in the manufacturing of bricks. It describes several research that changed the proportion of sludge used in place of clay or soil and how those changes affected the characteristics of bricks.

- Anwar *et al.* (2018): Bricks with a strong 29 MPa of strength and no heavy metal leaching were produced with a small 0.5% replacement of soil with sludge.

- Hossain *et al.* (2018): In a similar vein, bricks with a low strength of 1.5 MPa but higher water absorption were produced when 0.5% of the clay was replaced with sludge.

- Beshah *et al.* (2021): bricks with an 8.2 MPa strength were produced by replacing 10% of the sludge, and it was found that brick weight reduces as sludge content increases.

- Fatema *et al.* (2024): Bricks with a respectable strength of 15.33 MPa were formed with increased shrinkage when 9% sludge was substituted for clay.

Table 8. Utilization of textile sludge in brick industry

Materials used	Sludge content used	Max. Compressive Strength achieved in the study	Ref.
Textile sludge, soil, water	0.5%	29 MPa	(Anwar *et al.* 2018)
Textile sludge, clay, water	0.5%	1.5 MPa	(Hossain *et al.* 2018)
Textile sludge, clay, water	10%	8.2 MPa	(Beshah *et al.* 2021)
Textile sludge, clay, water	9%	15.33 MPa	(Fatema *et al.* 2024)

The combined data from Table 8 show that the proportion of textile sludge used in brick making has an impact on compressive strength; higher percentages result in weaker bricks and increased water absorption, weight fluctuation, and shrinkage.

3.9. Textile Sludge in Cement Industry

In this section, the studies done on using the sludge from textile industry in the cement industry is being discussed:

- Patel *et al.* (2012): This study highlighted that integrating 30%-70% textile sludge into the cement production process results in a wide range of compressive strengths for the blocks, from a weak 2.78 MPa to a moderate 17.42 MPa. The diminishing strength correlates with increasing sludge quantities, attributed to the sludge's zinc and lead salt content interfering with cement's hydration and consequent strength.

- Patil *et al.* (2022): Their research indicates a consistent decrease in compressive strength with higher sludge content within the cement mortar. This is due to calcium oxide's scarcity in the sludge. However, they also observed improved water absorption in the cement mortar, likely because the sludge particles fill up the voids in the mixture.

These studies provide insights into the possibilities and limitations of using textile sludge in cement-based applications, balancing environmental concerns with material performance.

4. DISCUSSION AND FUTURE PERSPECTIVES

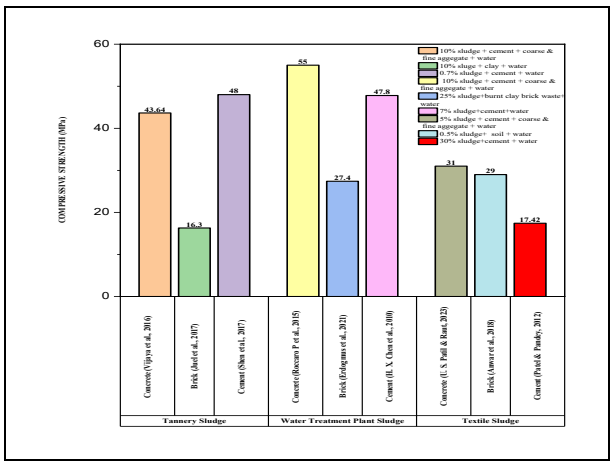


Fig. 1: Utilization of Various Industrial sludges in different Industries and maximum strength achieved

Fig. 1 shows the utilization of tannery, water treatment, and textile industry waste in the manufacturing of cement, bricks, and concrete being highlighted in the review. Tannery sludge generates strengths ranging from 24 to 43.64 MPa when used as fine aggregate in concrete, demonstrating how the grade of the concrete influences strength results. With strength values ranging from 10.8 to 55 MPa, water treatment sludge outperforms cement or water when used in place of fine aggregate. The optimum application for textile sludge is as a cement substitute in concrete; its strength ranges from 16.8 to 31 MPa. Compressive strength in brick manufacturing differs greatly depending on the kind of materials and techniques used. For example, mixes of soil and distilled water containing textile sludge have strengths of 29 MPa, which is higher than mixtures with clay and regular water (1.5 MPa). Similar to the fire of bricks, the process also affects the strength results, 4.46 MPa at 5% textile sludge. Because of its high lime concentration, water treatment sludge can increase brick strength by up to 11.6 MPa when 50% of clay is replaced. On the other hand, too much sludge during manufacture usually results in lower-quality building materials. The study highlights the significance of optimizing sludge use for sustainability, providing a sustainable substitute for conventional raw materials and aiding in efficient sludge disposal procedures.

5. CONCLUSION

This paper reviews how sludges from the tannery, water treatment, and textile industries can be repurposed in the manufacture of cement, concrete, and brick. It highlights:

- Bricks with 10-20% sludge content can be considered first-class due to their suitable water absorption rates, whereas 30% sludge content results in second-class bricks.
- The optimal burning temperature significantly affects the compressive strength of bricks, with 1000 °C yielding first-class bricks and lower temperatures resulting in lower classes.
- Utilizing water treatment plant sludge and untreated rice husk ash to produce bricks can decrease density while not significantly contributing to compressive strength.
- Research shows that adding up to 50% water treatment sludge in bricks can lead to compressive strengths over 3.5 MPa.
- In the cement industry, utilizing up to 10% water treatment plant sludge can produce cement blocks with high compressive strength and similar XRD patterns to ordinary cement.
- The chemical composition of water treatment plant sludge is beneficial, similar to clay, and can enhance the compressive strength of bricks when used appropriately.

This review paper evidently provides a comprehensive study on the sustainable use of industrial sludges to create construction materials while maintaining or improving their quality and performance.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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