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Material Selection for Penstocks in Hydropower Plants Using a Multi-Criteria Decision-Making Approach

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Abstract: *In hydropower plants, penstocks are used to convey water from a reservoir or dam to the turbines, where the water's kinetic energy is converted into mechanical energy. The material selection for penstocks is crucial to ensure their durability, resistance to corrosion, and ability to withstand high-pressure water flow. Several factors influence the choice of materials for penstocks Penstocks must be able to withstand high water pressures without failure. Therefore, materials with high strength and durability are preferred. Commonly used materials include steel alloys such as carbon steel, high-strength low-alloy (HSLA) steel, and stainless steel. Since penstocks are constantly exposed to water, they are susceptible to corrosion. Corrosion can weaken the structure and decrease its lifespan. Materials that exhibit excellent corrosion resistance, such as stainless steel or corrosion-resistant all oys (CRAs), are often chosen to mitigate this issue. Penstocks are typically fabricated by welding sections together. Therefore, the material should possess good weldability to ensure proper construction and maintenance. Carbon steel and stainless steel are commonly selected due to their favorable welding characteristics. The cost of materials plays a significant role in the selection process. While stainless steel and CRAs offer excellent corrosion resistance, they are often more expensive than carbon steel. Thus, the project budget and cost-effectiveness considerations may influence material choices. It's important to note that the selection of penstock materials is typically carried out by engineering professionals, taking into account the specific project parameters and requirements. They perform detailed analyses, considering factors like pressure ratings, material properties, and cost-effectiveness, to arrive at the most suitable material choice for each project. The research significance of penstock material selection in hydropower plants lies in its ability to ensure structural integrity, enhance performance, and mitigate corrosion-related challenges. The choice of materials directly impacts the safety and reliability of the penstocks, which are critical components in hydropower systems. By conducting research on penstock materials, engineers and researchers can identify and evaluate materials that exhibit high strength, durability, and resistance to corrosion. Furthermore, research on penstock materials also explores innovative and advanced materials, such as composite materials or new alloy formulations that could offer improved performance characteristics. These materials may exhibit superior strength, corrosion resistance, or other desirable properties that can enhance the efficiency and lifespan of penstocks. WASPAS (Weighted Aggregated Sum Product Assessment) is a multi-criteria decision-making (MCDM) method used to evaluate and rank alternatives based on multiple criteria. It is a widely used technique in various fields, including engineering, management, and decision sciences. Poly vinyl chloride (PVC), High-density polyethylene (HDPE), Glass reinforced plastic (GRP), Mild steel (MS) yield strength (YS), life (L), thickness (T), material cost(C), maintenance cost (MC) This result states" Rank" the of penstocks material selection in hydropower plants. Where First Rank is secured by GRP and last rank is secured by PVC whereas MS scored second one and HDPE followed it at third position.*

Keywords: *Power plant, WASPAS, PVC, GRP, HDPE, MS, YS*

1. INTRODUCTION

Water power is another name for hydropower. The following water from streams, rivers, dams, and other bodies of water is used to generate its electricity. Thus, the term "hydropower" describes the process of transforming the energy of moving water into another type of energy. Water has been utilized as an energy source for mills including gristmills, sawmills, and textile mills for thousands of years, and it is also used for irrigation. The installation of a hydro plant is a potential remedy in a variety of situations. The idea of utilizing water to turn a turbine and produce energy is known as hydropower. Through the hydrologic cycle and the inherent energy of flowing water, hydropower provides a dependable, domestic, emission-free source of clean, quick, and flexible electricity generation. Hydropower uses mechanical energy to transform the natural flow of water into electricity, which powers many types of industry and illuminates our houses. The turbine's blades are turned by the water's fall to generate electricity. The energy is transformed from the turbine into a generator, which then turns it into electricity. More power is generated the higher the flow and head.[13] Numerous materials are now readily available, and the choice of material is crucial in engineering and other professions. The challenge of choosing materials with the lowest cost and best performance is difficult [1]. For material selection for each component in any sector, an understanding of functional requirements and performance standards is required. The selection procedures take longer and are more difficult as there are more materials available [2,3]. The goal of the material selection process is to pick the best material for its low price, extended lifespan, minimal maintenance requirements, light weight, and high performance. By putting the MADM dilemma into words, the content that contains more than two options and attributes or criteria may be chosen [22]. A pipeline bifurcation typically has a stress magnitude that is 3–9 times larger than a conventional pipeline shell [7–10]. Special reinforcements are therefore offered to reduce the concentration of stress in key areas [7, 9]. Rarely are the penstocks of hydropower plants constructed in the first half of the 20th century fitted with this type of strengthening. Penstock failure may happen from a lack of reinforcement, particularly in situations when there is a fast pressure spike. A notable illustration of the linked strength issues is the breakdown of the penstock at the Lapino hydropower project in Poland [1]. During the rejection of the turbine load, the penstock ruptured where it connected to the turbine input pipe.[4] A well-proven technique called micro hydro has been used to electrify rural areas all over the world. It is a run-of-river system, which means no dams or storage facilities need to be built. Water is diverted from a river or stream, channelled into a valley, and then dropped into a turbine through a pipeline (Bracken et al. 2014). It can run independently of the grid and offer isolated populations clean, inexpensive renewable energy. Micro hydro provides a number of benefits over other energy sources, including the ability to be managed and maintained locally, comparatively cheaper maintenance and operating costs, and minimum environmental impact. The following traits describe probable locations that are suitable for the installation of micro hydro: placed near The World Data Bank [3] estimates that in developing nations, 800 million people still lacked access to electricity in 2019 despite electrification being a crucial priority for growth. The Covid-19 epidemic has recently had a substantial detrimental influence on the energy sector, notwithstanding the improvement obtained over the last years. Pressure on utilities, power providers, and other access providers at this time of governmental crisis has led to an increase in borrowing rates in nations with a significant access deficit [4]. Renewable Energy Resources (RES) can play a significant role in this situation by helping to reduce the amount of fundamental energy demands that must be covered. Organization for International Co-operation and Development.

2. MATERIALS AND METHODS

Poly vinyl chloride (PVC): PVC is a thermoplastic polymer widely used for its versatility, durability, and low cost. It is lightweight, chemically resistant, and has good electrical insulation properties. PVC is commonly used in piping systems, electrical cable insulation, window frames, flooring, and other construction applications. High-density polyethylene (HDPE): HDPE is a thermoplastic known for its high strength, chemical resistance, and excellent impact resistance. It has low moisture absorption, good UV resistance, and can withstand a wide range of temperatures. HDPE is commonly used in pipes, geomembranes, bottles, packaging materials, and various types of containers.

Glass reinforced plastic (GRP): GRP, also known as fiberglass reinforced plastic (FRP), is a composite material made of a polymer matrix reinforced with glass fibers. It offers high strength-to-weight ratio, corrosion resistance, and dimensional stability. GRP is used in applications requiring structural integrity and resistance to harsh environments, such as boat hulls, pipes, tanks, and automotive components.

Mild steel (MS): Mild steel is a carbon steel with low carbon content, making it relatively soft and ductile. It is widely used due to its affordability, machinability, and weldability. Mild steel has moderate strength and good formability, making it suitable for construction, automotive parts, machinery, and general fabrication applications. “The choice of material depends on the specific requirements of the application, including factors such as mechanical properties, chemical resistance, environmental conditions, cost, and manufacturing processes. Each material has its advantages and limitations, and selecting the most appropriate material involves considering these factors in relation to the desired performance and cost-effectiveness of the final product or structure”

Yield Strength (YS): Yield strength is a mechanical property that represents the maximum stress a material can withstand without permanent deformation or failure. It indicates the material's ability to resist yielding or plastic deformation under load. Higher yield strength generally indicates greater strength and structural integrity.

Life (L): Life, in the context of material selection, refers to the expected lifespan or durability of a material. It represents how long the material can perform its intended function without significant degradation or failure. Materials with longer life expectancy may be preferred for applications that require extended service life or have high maintenance and replacement costs.

Thickness (T): Thickness refers to the dimensions or gauge of a material. The thickness can impact the strength, rigidity, and durability of a structure or component. Thicker materials often offer increased strength and resistance to deformation or damage.

Material Cost (C): Material cost is the economic consideration associated with the purchase or acquisition of a material. It includes the raw material cost, manufacturing costs, and any additional expenses related to processing or fabrication. Material cost is an important criterion, as it affects the overall project budget and cost-effectiveness.

Maintenance Cost (MC): Maintenance cost refers to the expenses incurred in maintaining, repairing, or servicing the material or structure over its lifespan. Some materials may require frequent maintenance or have higher maintenance costs compared to others. Lower maintenance costs can contribute to long-term cost savings and improved operational efficiency. “When selecting materials, it is common to consider these criteria simultaneously and assign relative weights or priorities to each criterion based on the specific requirements and priorities of the application. Various decision-making methods, such as multi-criteria decision analysis (MCDA) or cost-benefit analysis, can be employed to evaluate and compare different materials based on these criteria, ultimately leading to an informed material selection decision”.

3. RESULTS AND DISCUSSION

TABLE 1. Penstocks Material Selection in Hydropower Plants

Materials	YS()Mpa	L(year)	T(mm)	C($/m)	MC($/m/year)
PVC	26	12	40	863.59	17.26
HDPE	34	25	46	1239.61	37.19
GRP	138	40	8	470.42	7.05
MS	252	50	9	630.65	37.84

Table 1 shows Alternative Parameters: Poly vinyl chloride (PVC), High-density polyethylene (HDPE), Glass reinforced plastic (GRP), Mild steel (MS). Evaluation parameters: yield strength (YS), life (L), thickness (T), material cost(C), maintenance cost (MC).

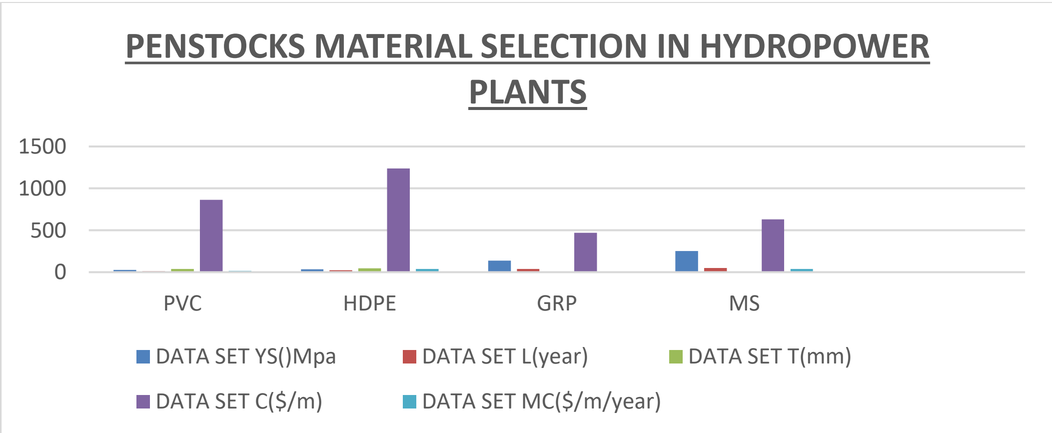

FIGURE 1. Penstocks Material Selection in Hydropower Plants

Figure 1 graphically shows: Alternative Parameters: Poly vinyl chloride (PVC), High-density polyethylene (HDPE), Glass reinforced plastic (GRP), Mild steel (MS). Evaluation parameters: yield strength (YS), life (L), thickness (T), material cost(C), maintenance cost (MC).

TABLE 2 . Performance value

Performance value				
0.10317	0.24000	0.86957	0.54473	0.40875
0.13492	0.50000	1.00000	0.37949	0.18971
0.54762	0.80000	0.17391	1.00000	1.00000
1.00000	1.00000	0.19565	0.74593	0.18645

Table 2 shows performance values show wide variability across observations. Some metrics remain low in early cases, indicating weaker performance, while later rows show strong improvements with values reaching 1.0. This suggests inconsistent performance initially, followed by better optimization and stabilization in subsequent evaluations.

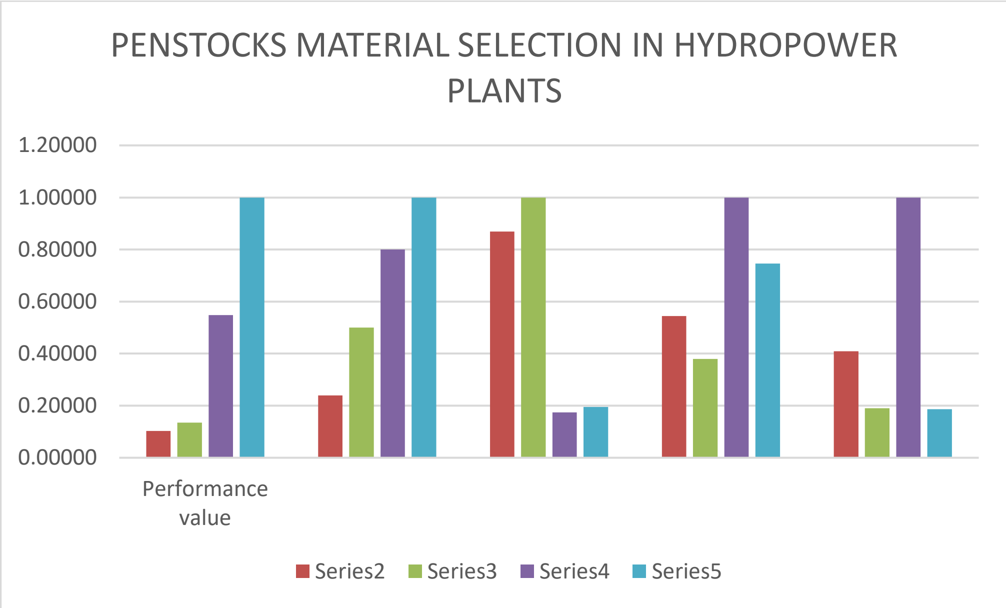

FIGURE 2. Performance value

Figure 2 compares the penstock material options based on several performance metrics. Series 4 consistently shows the highest scores, indicating its superior suitability. Series 5 excels in specific performance aspects, while Series 2 and Series 3 show moderate performance; this illustrates the trade-offs between strength, cost, and performance in material selection.

TABLE 3 .Weight

Weight				
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20

Table 3 shows uniform weighting across all criteria, with each parameter assigned an equal weight of 0.20. This indicates that all factors are considered equally important in the evaluation process, ensuring a balanced and unbiased decision-making approach without prioritizing any single criterion over others.

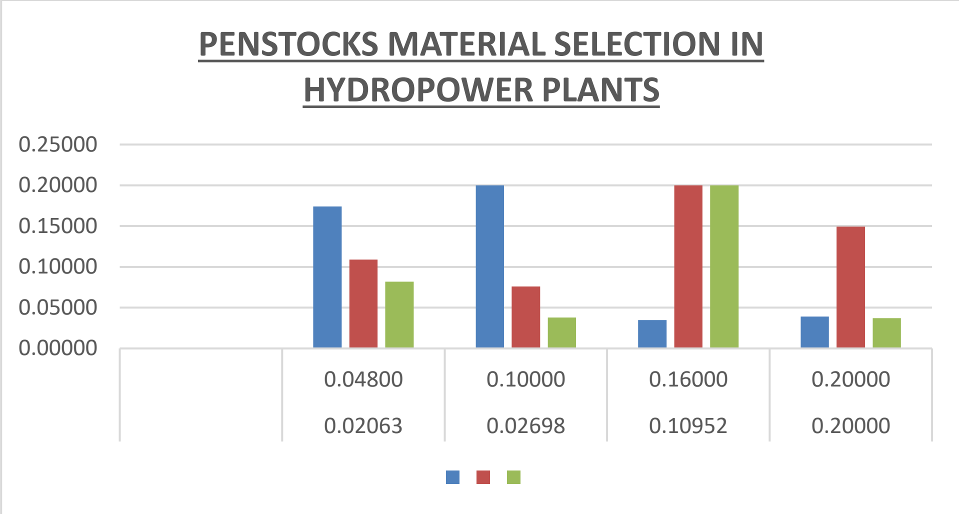

FIGURE 4. Weighted normalized decision matrix

Figure 4 shows diagram illustrates that in the Benstock material selection process, equal weight (0.20) has been assigned to all criteria in rows 2 through 5 of Table 4. This reflects a balanced evaluation framework, where each performance factor is considered equally important, and bias towards any particular criterion in the decision-making process is avoided.

TABLE 5 .WASPAS Coefficient

Preference Score	Preference Score	WASPAS Coefficient
0.4332	0.3437	0.3885
0.4408	0.3446	0.3927
0.7043	0.5976	0.6509
0.6256	0.4863	0.5560

Table 5 presents WASPAS coefficients derived from two preference scores. The third alternative achieves the highest WASPAS value (0.6509), indicating the best overall performance. The fourth alternative ranks second, while the first and second alternatives show comparatively lower scores, reflecting moderate suitability in the evaluation process.

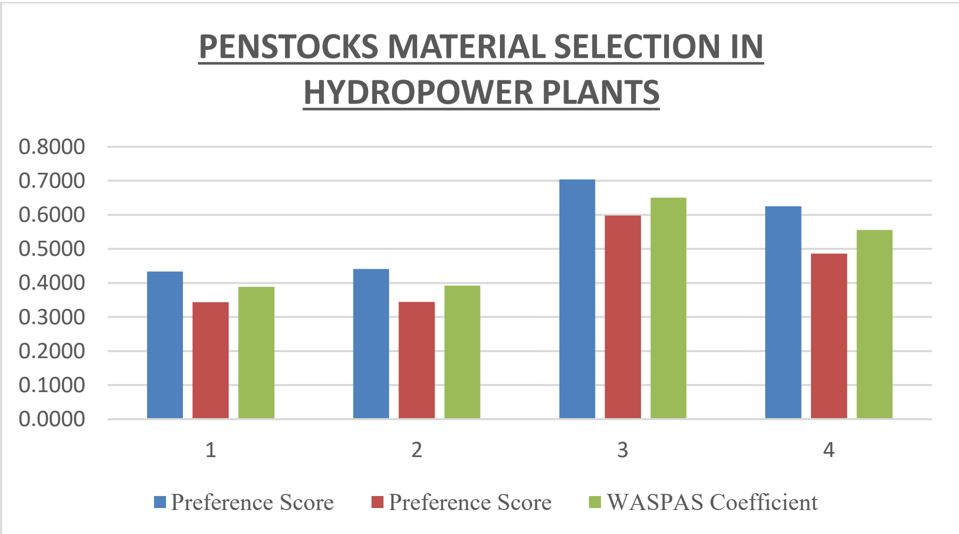

FIGURE 6 .WASPAS Coefficient

Figure 6 shows the" Preference Score, Preference Score, WASPAS Coefficient "of penstocks material selection in hydropower plants.

TABLE 6 Rank

Alternatives	RANK
PVC	4
HDPE	3
GRP	1
MS	2

Table 6 shows Rank the of penstocks material selection in hydropower plants. Where First Rank is secured by GRP and last rank is secured by PVC where as MS scored second one and HDPE followed it at third position.

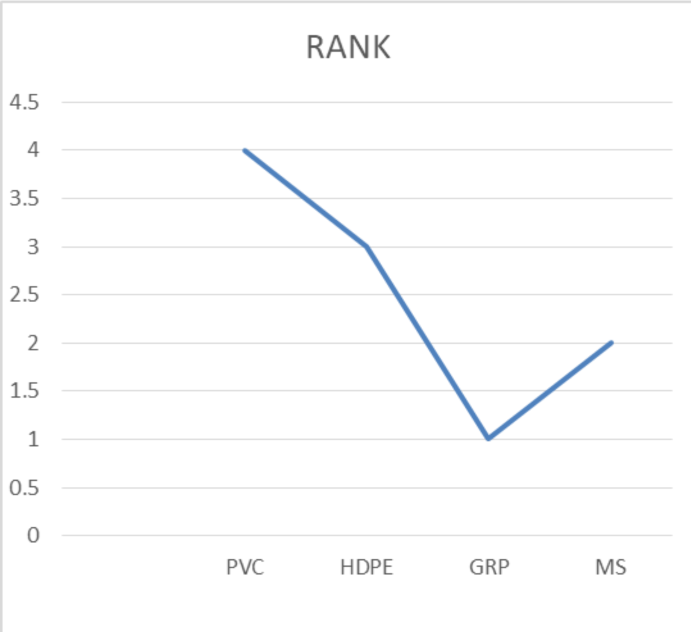

FIGURE 7. Rank

Figure 7 shows Rank the of penstocks material selection in hydropower plants. Where First Rank is secured by GRP and last rank is secured by PVC whereas MS scored second one and HDPE followed it at third position.

4. CONCLUSION

In conclusion, the material selection for penstocks in hydropower plants plays a crucial role in ensuring the structural integrity, performance, and longevity of these critical components. The choice of materials involves considering factors such as strength, corrosion resistance, weldability, cost, and operational environment. By conducting research and analysis on penstock materials, engineers and researchers can identify materials that exhibit the necessary properties to withstand high water pressures, resist corrosion, and meet project-specific requirements. This research contributes to the development of guidelines, standards, and best practices for penstock material selection, enhancing the safety and reliability of hydropower plants. The significance of penstock material selection lies in its impact on structural integrity and safety, efficiency and performance, as well as the mitigation of corrosion-related challenges. Proper material selection ensures that penstocks can withstand the demanding conditions of high-pressure water flow and harsh operating environments. Moreover, the economic considerations of material and maintenance costs are also essential in material selection, as they influence the overall project budget and cost-effectiveness. Balancing these factors allows for informed decision-making, considering the long-term operational and maintenance requirements of the hydropower plant. In summary, the research significance of penstock material selection in hydropower plants lies in its contribution to ensuring the safety, efficiency, and durability of these crucial components, ultimately optimizing the performance and reliability of hydropower systems.

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