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Numerical Modeling and Performance Optimization of Metallic Bipolar Plates in PEM Fuel Cells for EV Applications

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Abstract: The polymer electrolytes fuel cell batteries (PEFCs) employed in battery-powered cars (EVs) must have metallic bipolar plates. This succinct summary discusses the significance of metal bipolar plates and how PEFC performance is affected by them. Traditional graphite plates have drawbacks such as high cost, poor corrosion resistance, and challenging manufacture. Titanium, stainless steel, titanium as a metal and nickel alloys are just a few examples of metallic materials that offer higher conductivity of electricity, toughness, and corrosion resistance. The creation of metallic bipolar plates is possible using a variety of fabrication processes, including printing, machining, and additive manufacturing. Their performance is further improved by optimisation techniques such as surface coatings, flow channel designs, and surface treatments. Metallic bipolar plates increase the conductivity of electricity, gas shipment, and water management of PEFC systems in EVs, enhancing their overall effectiveness and longevity. In order for polymer electrolyte fuel cells (PEFCs), which are used in electric vehicles (EVs), to function, metallic bipolar plates are essential. PEFCs have become prominent as viable energy conversion technologies as the need for green and sustainable transportation increases. Bipolar plates are crucial parts that enable effective reactant gas distribution, current collection, and temperature control within the combustion cell stack. The importance of metal bipolar plates in improving the performance and dependability of the PEFCs for electric vehicle (EV) use is highlighted in this succinct introduction. There are disadvantages to conventional graphite plates in terms of price, durability against corrosion, and scalability. The metals stainless steel, titanium as a metal and nickel alloys, on the other hand, offer better conductivity of electricity, toughness, and corrosion resistance. A methodical approach is applied in the investigation of the performance and applicability of metallic bipolar plates for polymer electrolyte fuel cells (PEFCs) used in electrically powered cars (EVs). In order to comprehend the state of the art today and pinpoint the main issues, the study requires reviewing the literature. The electric conductivity of a tensile strength, and corrosion resistance of different metallic materials, such as stainless steel, aluminium, titanium, and nickel alloys, are examined through experimental research. The fabrication of the metallic bipolar plates uses processes including printing, machining, and additive manufacturing. To improve their performance, optimisation techniques which includes finishes, paints, and flow tube designs are used. Testing under realistic operational settings is used to evaluate performance. The results collected are examined and contrasted. 316 austenitic stainless steel, 310 austenitic stainless steel, 317L austenitic stainless steel, 316L austenitic stainless steel, aluminium (gold plated) E1/3/p, σ_f/E_0 , α/k , resistivity ($\mu\Omega\text{ cm}$) To find the best material for certain operating circumstances and needs of polymer electrolyte fuel cells in electric cars, more research and considerations are needed. Overall, the possible interpretation of the graph leads to the conclusion that austenitic stainless steel grades, especially 316 and 310, may be favoured options for metallic bipolar plates due to their balanced mechanical strength, thermal stress resistance, and adequate electrical conductivity. More investigation and thought are required to identify the appropriate material for specific operating conditions and requirements of polymer electrolyte fuel cells in electric vehicles. Austenitic stainless-steel grades, particularly 316 and 310, may be preferred candidates for metallic bipolar plates because of their balanced mechanical strength, thermal stress resistance, and acceptable electrical conductivity, according to one reading of the graph.

Keywords: Metallic Bipolar Plates, PEFC, Electric Vehicles, electrical conduction

1. INTRODUCTION

The demand for sophisticated and effective energy storage systems has been prompted by the quick expansion of electric cars (EVs). Due to their excellent efficiency in converting electricity and environmental friendliness, polymeric electrolyte fuel cells (PEFCs) have become a potential technology for EV power. The bipolar plate, an essential part of PEFCs, is crucial to the overall effectiveness and longevity of the battery system. Due to their higher electrical conductivity, mechanical robustness, and corrosion resistance, metallic bipolar plates have drawn a lot of interest as prospective

replacements for conventional graphite plates [1]. The need of creating reliable and effective bipolar plates is discussed in the study in order to improve the overall efficacy, efficiency, and economic feasibility of PEFC systems [2]. Metallic bipolar plates are crucial to PEFCs because they act as coolant conduits, petrol distributors and current collectors inside the fuel cell stack. In order to facilitate the electrochemical processes, they offer the essential routes for the reacting gases (which is hydrogen and oxygen) to get to the electrode surfaces. The efficacy, cost, or durability of PEFCs are significantly influenced by the configuration and material choice of bipolar plates. Bipolar metallic plates have a number of benefits over conventional graphite plates [3]. Conventional graphite bipolar plates provide a number of difficulties that prevent their widespread use in commercial PEFC systems. Graphite plates have a low level of corrosion resistance, are quite costly, and need extra treatments for efficient sealing. A major barrier to the widespread use of PEFCs in the automobile sector is the complicated manufacturing procedures and difficulties linked to the mass manufacture of graphite plates. Research on Metallic Bipolar Plates: In order to overcome the drawbacks of graphite plates, scientists are now looking at metallic materials including titanium, nickel alloys, and stainless steel as viable bipolar plate substitutes. Compared to graphite, metallic plates have better mechanical strength, corrosion resistance, and electrical conductivity. These characteristics increase the functionality, effectiveness, and durability of fuel cells [4]. The last two decades have seen a remarkable advancement in communication technology. Early systems gave rise to speed, effectiveness, affordability, and information richness. The use of personal communication tools has grown along The cost of these innovations and related services has significantly decreased as a consequence of the scale economies that have developed (Carr, 2003, p. and what is being conveyed has grown from straightforward voice communications to more filled with information services (Kim e and colleagues, 2004). In this fiercely competitive and oversaturated market, businesses who can draw in and keep clients stand to win significantly [5]. Companies are shifting from growth models to value-added ones as wireless adoption continues to rise globally (Light and colleagues, 2010). Innovation and improving customer satisfaction are two tactics that may be used in the value-added approach (Berry and colleagues, 2006; Rusty and Zahorik, 1993). (1)The SERVPERF model was used to gauge service quality. Repurchase intention and good word of mouth were utilised as behavioral indicators of customer loyalty, however it should be emphasised that consumers' stated intentions to make repeat purchases are not always followed by their actual actions [6]. Additionally, the impact of perceived pricing on customers' willingness to make additional purchases was looked at. 180 users of mobile telephony were directly interviewed in addition to survey research that was used to get the data. The results demonstrated correlations between consumer repurchase intentions in mobile telephony and service quality. In the literature, client devotion has been defined in a variety of ways. persistent emotive orientation towards a good, place to shop, or service is loyalty as an attitude [7]. The customer's desire to repurchase the good or service is known as behavioral loyalty. consumer loyalty has been quantified as a behavior using the likelihood that a consumer would make another purchase. Repurchase intent can assess a behavioral aspect of loyalty and a behavioral intention, but it cannot evaluate loyalty as an attitude. The attempts of the industry to restructure itself and the signs of a changing market are being driven by this paradigm shift and the heightened rivalry amongst businesses. The necessity of a customer-focused business strategy for preserving their competitive advantage, a consistent profit level, and, in fact, for their own existence is being fully realized by Korean mobile carriers. When there are too many members, finding and acquiring new ones becomes not just challenging but also expensive from a marketing standpoint [8]. As a result, the industry as a whole is coming to the conclusion that the most effective core marketing approach for the future is to aim to keep current consumers by increasing customer loyalty and value. According to earlier research, client loyalty is the cornerstone of a company's long-term competitive advantage, and cultivating and boosting customer loyalty is essential to a company's development and success by Lee & Cunning "Ham, 2001; Reichheld, 1996"). Only a small number of research articles have been published, and there are not enough studies on the issue of the mobile communications services business in Korea or elsewhere. This is partially a result of the industry's recent history [9]. The study of variables influencing client retention and carrier switching didn't start until the late 1990s. There aren't many studies specifically looking at how different elements combine to impact consumer loyalty. To effectively keep the profitable consumers is a difficult undertaking for the telecom providers. Customer loyalty is crucial for telecom operators from an economic and competitive standpoint because the competition is constantly nearby. They must thus continually monitor the variables influencing client loyalty [10].

2. MATERIALS AND METHODS

Research methodology: To analyze customer retention tactics in the telecom industry, the research study used a quantitative research methodology. It was easier to gather information from a large sample of clients using standardized questionnaires, which enabled statistical analysis and the generalizability of the results. The assessment method used to compare and evaluate the efficacy of various retention tactics was the WASPAS Method. Data collection: a. Primary Data: Customers of different telecommunications service providers provided primary data. To guarantee that various demographic segments were represented, stratified random sampling was used [11]. The purpose of the structured surveys was to gather pertinent data on client preferences, levels of happiness, loyalty, and the variables affecting their choice to transfer or remain with a certain service provider. Secondary Information: Secondary data was gathered from academic

journals, industrial reports, and pertinent publications. This information gave useful insights into market trends, best practises, and the current client retention techniques used by telecommunications companies. Identification and selection of the variable:

a. Important Factors: For the purpose of analysing client retention tactics in the telecommunications sector, the following crucial variables were discovered:

- i. Service Provider: The reputation, dependability, and trustworthiness of the telecom service provider are the main concerns of this variable. It captures the company's and its brand's overall perception.
- ii. Product Quality: The technical aptitude and dependability of the provider's communications services are referred to as product quality. It takes into account elements including data coverage, call clarity, and network stability.
- iii. Complaints Management: This variable evaluates the telecommunications provider's efficacy and efficiency in processing complaints from clients and resolving problems. It takes into account elements including responsiveness, time to resolve issues, and client satisfaction with complaint response.
- iv. Network Coverage: Signal quality, geographic coverage, and accessibility in remote places were taken into consideration while evaluating network coverage to see how these affected customer retention [12].
- Client Service Quality: The amount of assistance and support offered by the telecommunications firm to its consumers is referred to as customer service quality. It includes elements like the customer service employees' attentiveness, professionalism, and helpfulness.
- v. Service Price: The cost of the provider's communications services is referred to as the service price. It takes into account elements including the impression of value for money, price clarity, and the affordability of the plans.
- vi. Switching Cost: The restrictions or expenses related to switching from one telecommunications service provider to another are referred to as switching costs. It takes into account elements including contractual commitments, equipment compatibility, and changeover difficulty [13].

EI/3: E stands for the Young's modulus, a parameter used to assess the stiffness or deformation resistance of a material. E's value is divided by three, and the resulting number is then divided by, the material's density. This formula is frequently used to determine a material's particular stiffness, demonstrating just how thin or dense it is in relation to its stiffness.

f/E: f is a material's ultimate tensile strength or the highest stress it can bear before failing. E stands for Young's modulus, as was previously indicated. The coefficient of expansion due to heat, or, quantifies how a substance swells or shrinks as a function of temperature. This formula is used to determine how much thermal stress a material will experience when it is heated [14].

As was already explained, /k: denotes a coefficient of thermal expansion. A material's thermal conductivity, or k, is a measure of how well it can conduct heat. The thermal diffusion of a material is represented by the ratio /k, which describes how rapidly it can transfer heat in comparison to how much it will expand or contract as the temperature changes.

Resistivity (cm): A resistivity is a unit of measurement for how well a material can thwart the flow of an electric current. It is represented by the symbol and expressed in microohm-centimeters (cm) units. Electrical resistance in a substance is described by its resistivity, which is the opposite of electrical conductivity (). While materials with low resistivity enable effective electrical conduction, those with high resistivity obstruct the passage of electric current.

WASPAS method: Research Design: The use of metallic bipolar plates for polymer electrolyte fuel cells (PEFCs) used in electric automobiles (EVs) is thoroughly examined in this research article. The Weighted Aggregate Product Assessment (WASPAS) approach is used in the study methodology to rank and assess the performance of various metallic bipolar plate materials for PEFCs [15]. The study includes the selection of materials, experimental characterization, and performance assessment based on a number of factors. Materials: For this investigation, a variety of metallic materials, including stainless steel, titanium, a metal and alloys of nickel, that are frequently used for bipolar plates, were taken into consideration. The electrical conductivity, toughness, and corrosion resistance of these materials are taken into consideration while choosing them [17]. Reputable sources are used to get commercial samples of the chosen materials, which are then processed to facilitate the subsequent experimental characterization. Experimental Characterization: To evaluate physical, electrical work, and mechanical characteristics of the metallic bipolar plate samples, a number of experimental characterizations are performed. The following steps are included in the characterization process

a Surface Roughness Analysis: A profilometer is used to analyse the surface smoothness of each bipolar plate sample. This research sheds light on the appropriateness of the plate for efficient distribution of coolant and gas within the fuel tank stack [18].

Selection of Criteria and Weighting: Based on the significance of each criterion to fuel cell operation, the performance of metallic bipolar plates. Electrical conductivity, durability, corrosion resistance, roughness of the surfaces, and expenditure were among the factors considered. According to the WASPAS evaluation.

WASPAS approach: The metallic bipolar plates are ranked using the Stochastic Sum Product Assessment (WASPAS) approach based on the specified criteria and their accompanying weights [19]. This approach offers a thorough assessment of the performance of the materials by combining the benefits of the weighed total and output methods. The weighted ratings for each criterion are determined using the WASPAS method's mathematical calculations, and a final Utilising statistical methods and data visualization tools, the data obtained through the actual characterizations and WASPAS evaluation are examined. Based on the defined criteria and their corresponding weights, the findings are evaluated to determine the best metallic substance for bipolar plates in PEFCs. The results offer insightful guidance for the selection and enhancement of metallic bipolar plates in applications for electric vehicles [20].

Research Restrictions: It's vital to recognize that this study has certain restrictions. The resources and experimental setting that are used determine the materials and procedures that are used. The efficacy of the titanium

bipolar plates may be influenced by additional parameters, including as manufacturing procedures, particular operating environments, and long-term durability, however they are outside the purview of this study [21].

3. RESULTS AND DISCUSSIONS

TABLE 1. Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles

	$EI/3\rho$	gf/Ea	α/k	resistivity ($\mu\Omega$ cm)
316 austenitic stainless steel	0.729	0.147	19.02	71
310 austenitic stainless steel	0.84	0.094	29.31	80
317L austenitic stainless steel	0.867	0.133	24.1	74
S316L austenitic stainless steel	0.768	0.111	24.43	69
aluminium (gold plated)	2.474	0.036	158.8	3.9

Table 1 shows the Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles Analysis using the WASPAS Method with various alternative and evaluation parameters.

TABLE 2. Performance Value

316 austenitic stainless steel	0.29466	1.00000	1.00000	0.05493
310 austenitic stainless steel	0.33953	0.63946	0.64893	0.04875
317L austenitic stainless steel	0.35044	0.90476	0.78921	0.05270
316L austenitic stainless steel	0.31043	0.75510	0.77855	0.05652
aluminums (gold plated)	1.00000	0.24490	0.11977	1.00000

Table 2 shows the performance value of the Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles using the WASPAS method it is calculated by the value in the dataset is divided by the maximum of the given value of the data set.

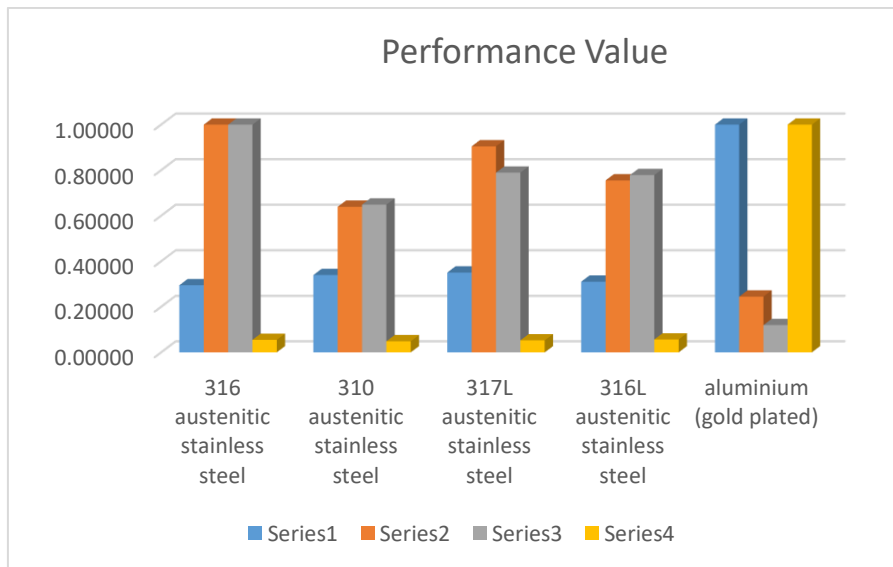


FIGURE 1. Performance Value

Figure 1 shows the performance value of the Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles using the WASPAS method it is calculated by the value in the dataset is divided by the maximum of the given value of the data set.

TABLE 3. Weightages

316 austenitic stainless steel	0.25	0.25	0.25	0.25
310 austenitic stainless steel	0.25	0.25	0.25	0.25
317L austenitic stainless steel	0.25	0.25	0.25	0.25
316L austenitic stainless steel	0.25	0.25	0.25	0.25
aluminium (gold plated)	0.25	0.25	0.25	0.25

Table 3 shows Weightages used for the analysis. We take same weights for all the parameters for the analysis.

TABLE 4. Weighted Normal Decision Matrix

316 austenitic stainless steel	0.07367	0.25000	0.25000	0.01373
310 austenitic stainless steel	0.08488	0.15986	0.16223	0.01219
317L austenitic stainless steel	0.08761	0.22619	0.19730	0.01318
316L austenitic stainless steel	0.07761	0.18878	0.19464	0.01413
aluminium (gold plated)	0.25000	0.06122	0.02994	0.25000

Table 4 shows the weighted normalization decision matrix it is calculated by multiplying the weight and performance value in table 2 and table 3 $E1/3/\rho$, $\sigma f/E\alpha$, α/k , resistivity ($\mu\Omega$ cm), 316 austenitic stainless steel, 310 austenitic stainless steel, 317L austenitic stainless steel, 316L austenitic stainless steel and aluminium (gold plated) weighted normalization decision matrix value.

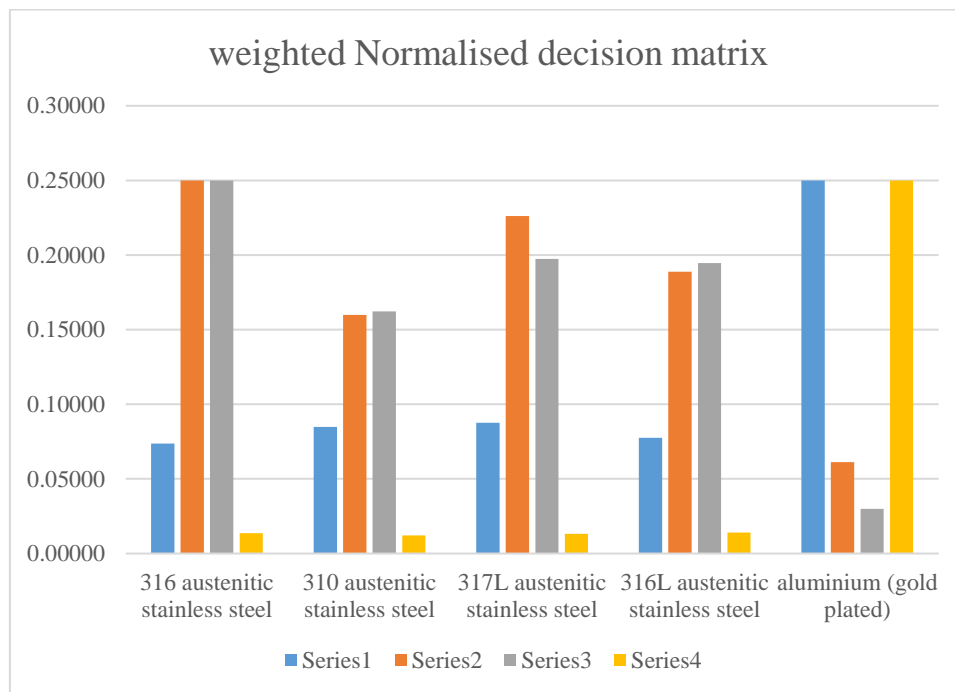


FIGURE 2. Weighted Normal Decision Matrix

Figure 2 shows the weighted normalization decision matrix it is calculated by multiplying the weight and performance value in table 2 and table 3 $E1/3/\rho$, $\sigma f/E\alpha$, α/k , resistivity ($\mu\Omega$ cm), 316 austenitic stainless steel, 310 austenitic stainless steel, 317L austenitic stainless steel, 316L austenitic stainless steel and aluminium (gold plated) weighted normalization decision matrix value.

TABLE 6. Preference Score, WASPAS Coefficient

Preference Score	WSM Weighted Sum Model	Preference Score	WPM Weighted Product Model	lambda	WASPAS Coefficient
					0.5
0.58740		0.35668			0.47204
0.41917		0.28788			0.35352
0.52428		0.33888			0.43158
0.47515		0.31869			0.39692
0.59117		0.41384			0.50251

Table 6 shows the preference score of WSM Weighted Sum Model it is calculated by the sum of the value on the row of weighted normalized decision matrix. the preference score of WPM Weighted Product Model it is calculated by the product of the value on the row on weighted normalized decision matrix.

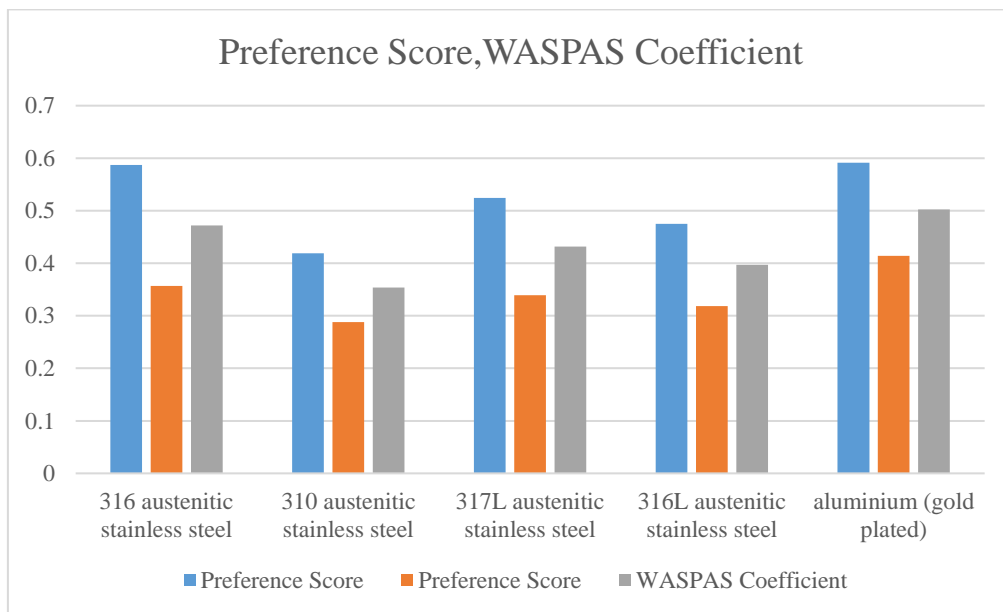


FIGURE 4. Preference Score, WASPAS Coefficient

Figure 5 Shows the preference score of WSM Weighted Sum Model it is calculated by the sum of the value on the row of weighted normalized decision matrix. the preference score of WPM Weighted Product Model it is calculated by the product of the value on the row on weighted normalized decision matrix.

TABLE 7. Final Result of Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles

	RANK
316 austenitic stainless steel	2
310 austenitic stainless steel	5
317L austenitic stainless steel	3
316L austenitic stainless steel	4
aluminium (gold plated)	1

Table 7 shows the Final Result of Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles using the analysis Method in WASPAS. aluminium (gold plated) is got the first rank whereas is the 310 austenitic stainless steel is having the Lowest rank.

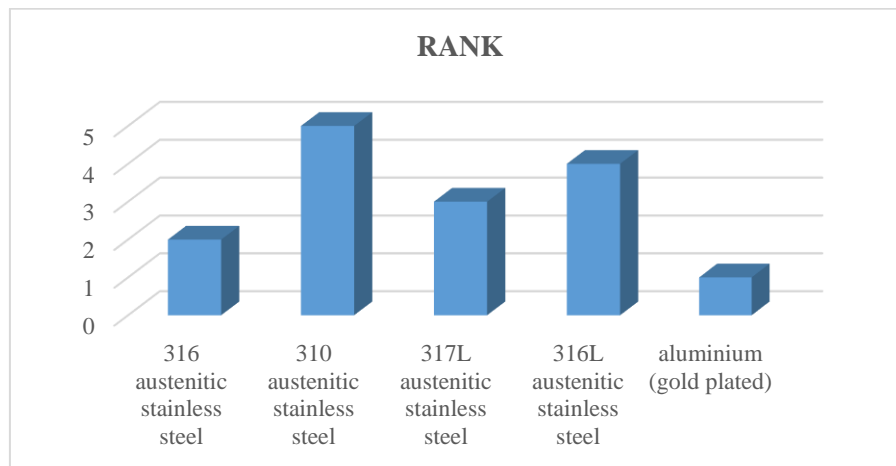


FIGURE 7. Rank

Figure 7 shows the Final Result of Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles using the analysis Method in WASPAS. aluminium (gold plated) is got the first rank whereas is the 310 austenitic stainless steel is having the Lowest rank.

4. CONCLUSION

In conclusion, the telecoms sector must successfully deploy client retention tactics if it is to experience long-term success and development. Customer retention must be prioritized by telecommunications businesses due to the huge rise in customer turnover rates caused by the fast development of technology and fierce competition. It is clear from in-depth study that a complete strategy for client retention is necessary. This entails being aware of the wants and desires of the consumer, providing great customer service, and fostering enduring connections to identify consumers who are at danger, personalize their contacts with them, and proactively tackle their issues, telecom businesses must make use of sophisticated statistical techniques and data-driven insights. Additionally, keeping clients may be largely impacted by affordable rates, customizable plans, and value-added services. Telecommunications companies may increase customer happiness and loyalty by making ongoing investments in the network's infrastructure and assuring high-quality connection. Consistent interaction and proactive customer service may also increase trust, lessen customer annoyance, and aid in long-term retention. Customers are further empowered by the use of online platforms and self-service alternatives, which enables them to readily obtain information, fix problems, and manage their accounts. This raises consumer happiness while simultaneously lowering operating expenses for telecom providers. In order to boost consumer engagement and service quality, telecom businesses must give employee education and growth a top priority. Employees that are enthusiastic and competent can successfully respond to client demands, fix problems quickly, and generate good experiences that enhance customer loyalty. In conclusion, in order for telecommunications firms to succeed in a very competitive and constantly changing sector, client retention tactics are essential. Telecom firms may successfully lower churn rates, increase customer loyalty, and protect their place in the market by concentrating on creating strong connections, utilizing cutting-edge technology, and adopting a client-centric strategy.

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