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EXPERIMENTAL AND COMPUTATIONAL STUDY ON BIOFUEL-INDUCED CORROSION IN AUTOMOTIVE FUEL TANKS

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ABSTRACT

The present research investigates the corrosion behavior of carbon steel at ten different temperatures, including 50 °C, 60 °C, and ambient temperature. Immersion tests were conducted for 720 hours in pure diesel, 50% biodiesel-diesel blend, and pure biodiesel. After the exposure period, corrosion performance was evaluated by measuring weight loss of the metal samples. Additionally, the acidity and oxidation behavior of the biofuels were analyzed using microscopic techniques and computational fluid dynamics (CFD) oxidation analysis, respectively. The fuel tank surface was examined using optical microscopy, scanning electron microscopy (SEM), and energy-dispersive spectroscopy (EDS). The results indicate that corrosion of mild steel increases with rising temperature, while the influence of water content and oxidation products on corrosion was assessed through a combination of experimental observations and simulation studies.

Key words: Fuel tank, Biofuel, Corrosion, SEM,

1. INTRODUCTION

Current trends indicate that alternative fuels are being increasingly adopted in the automotive industry to reduce pollution, with biofuels gaining importance as either a full or partial replacement for diesel fuel. However, a major challenge is the corrosion of modern materials in biodiesel, which can reduce vehicle efficiency. Corrosion is the degradation of a metal caused by a chemical or electrochemical reaction with its environment. Even in the absence of a separate cathodic metal, iron corrodes, as corrosion is inherently an electrochemical process. On a steel surface, anode-cathode pairs can form at regions with different electrochemical potentials or tendencies to oxidize. In a galvanic cell, when oxygen and moisture are present and two dissimilar metals, such as iron and copper, are electrically connected, distinct chemical reactions occur at the surfaces of each metal, producing a flow of electrons through the connecting wire. The following anodic reaction occurs at the iron surface, or anode, when iron is oxidised:

$$2Fe - 4 \text{ electrons} \rightarrow 2Fe^{++} \quad (1)$$

The following cathodic reaction takes place at the copper surface, or cathode, when oxygen is reduced:

$$0_2 + 2H_20 + 4 \text{ electrons} \rightarrow 4OH^- \quad (2)$$

According to Eq. 1.1, the anode is where the process's actual metal loss occurs. In the solution around the anode, the iron atoms are changed into ferrous ions (Fe++), which dissolve. According to the following net redox reaction,

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they may diffuse and mix with the hydroxyl ions (OH-), leading to the precipitation of ferrous hydroxide [Fe(OH)2]:

$$2Fe + 0_2 + 2H_20 \rightarrow 2Fe(OH)_2 \quad (3)$$

Rust is created by further oxidising the hydrous ferrous oxide (FeOH20) created by Eq. 3 to create hydrous ferric oxide (Fe203. nH20). The most prevalent type of steel corrosion is general corrosion, also known as rusting. Numerous micro corrosion cells are triggered at the corroded area in what might be considered a uniform corrosion process. Small granules that typically have the anode as their boundary might be the cells, for instance.

2. LITERATURE REVIEW

Compared to conventional gasoline and diesel, biodiesel offers significant advantages and is considered an environmentally friendly alternative. Its use in compression ignition engines allows for the replacement of non-renewable fossil fuels [1]. The main feedstocks for biodiesel are vegetable oils and animal fats. However, due to their high viscosity and low volatility, these raw oils and fats cannot be used directly in diesel engines, as they cause engine deposits, piston ring sticking, and injector blockage [2]. To overcome these limitations, triglycerides are converted via catalyzed transesterification with alcohol to produce mono-alkyl esters, commonly known as biodiesel. These esters of long-chain fatty acids resemble conventional hydrocarbon diesel and provide comparable engine performance while emitting fewer pollutants [3]. The main biodiesel feedstocks include canola, palm, soybean, cottonseed, and rapeseed oils, which have some of the highest heating values (HHV) among biofuels. Additionally, biodiesel has lower sulfur content, ranging from 39 to 49 mg/kg, contributing to its environmental benefits [4].

The gasoline, which has a 46 mg/kg concentration in all types of vegetable oils can be used to substitute diesel oil, although palm and grape seed oils are best for use as a diesel fuel extender or additive [5]. Biodiesel is referred to as the clean fuel because its sulphur concentration is comparably lower than that of petroleum diesel and it contains no genic chemicals. When used in CI engines, the capability of biodiesel to be extremely biodegradable plus its superior oiling quality make it a wonderful fuel. Petrol and diesel have many physiochemical characteristics, which has disclosed its potential and practical usage as a fuel to replace petroleum diesel in the near future [6]. If the physical and chemical characteristics of biodiesel meet the requirements of the international standard biofuel specification. It might serve as a substitute fuel for compression-ignition diesel engines. Before being used as an alternate fuel, biofuel must meet the requirements set forth by (ASTM), BS71-3, and EN14214 [7]. The characteristics of biofuel include higher heating value (HHV), distillation range, total glycerine content, copper common flash point, free glycerine content, sulphur content cloud carbon residue acid value, ash content and viscosity density centre [8].

Biodiesel and petroleum diesel fuel have equivalent physiochemical properties. The most coveted differentiating characteristic of biodiesel fuel is its viscosity since it significantly affects how fuel injection equipment functions, especially at lower temperatures. The fuel's fluidity is reduced when viscosity increment. Otherwise, the higher viscosity of the fuel spray results in poor atomization. The accuracy of the operation is directly impacted by this. However, because biodiesel naturally has a lower viscosity, it has made it simpler to pump, automate, and generate

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finer droplets [9]. The atomizer of fuel in the ignition chamber, the stickiness of fuel, and the lubricating properties of engines are all hampered by higher viscosity values. The range of the international standard specification should therefore be maintained for biodiesel values [10].

The methyl or ethyl esters are linked to triglycerides through the transesterification process and have a molecular weight that is roughly eight times smaller than that of vegetable oil [11]. Viscosity fuels made from animal fats, such as those derived from land animals, display the same bias at temperatures greater than those of ordinary diesel and necessitate significant engine modification. Because vegetable oil burns uncleanly in a diesel engine, unwanted substances like acrolein and organic acid are formed. Burning of vegetable oil is the primary cause of the detrimental impacts on the longitudinal engine's performance. Fuel for diesel engine applications can be made without significant alterations if the fatty acid methyl esters are made from vegetable oil using the transesterification process [12].

Storage is very interested in the position of the feature of biodiesel throughout the process of oxidisation and chemical action of biodiesel provided at the phase of combustion. These issues cause the acid version of this environmentally favorable fuel to transform into sediments and gum that won't dissolve, which can block carbon filters. However, oxidation and polymerization happen because unsoaked fatty acid chains are nearby and the parent molecule has strong double bond properties, which rapidly react with oxygen as soon as it is exposed to air [13].

Many methods are used to oxidize the chain of fatty acids, which is a difficult process, according to Jain and Sharma (2010b). Numerous elements, such as light, temperature, unrelated substances, peroxides, and the size of the surface area between the biodiesel and air, contribute to the oxidation growth of the biodiesel. The greatest ways to boost the oxidative firmness of biodiesel, according to the authors, include consciously increasing antioxidants and changing the fatty ester strikingness [15].

3. FUEL TANK MATERIAL

Diesel fuels shouldn't be utilised with zinc, either as plating or as a significant alloying component. In the presence of sulphur, zinc is unstable, especially if the fuel contains moisture. The internal engine parts are severely harmed by the sludge created by chemical reaction.Steel's resistance to corrosion in fuel tanks for automobiles has been questioned by automakers. Some additives that may be used in the manufacturing of biodiesel may hasten the development of corrosion. Figure 3.2 is an example of a common gasoline tank leak brought on by corrosion. Two bench-scale simulative tests were utilised to evaluate the resistance to external corrosion: the Neutral Salt Spray test (ASTM B117) with exposures up to 2000 hours and the Cyclic Corrosion test (SAE J2334) with exposures up to 120 and 160 cycles . The latter exposures were chosen to represent a 15- and 20-year road life, respectively. The failure criterion of perforation was adopted. To examine the quantitative development of corrosion, pit depths were measured over the coating integrity, entire specimen was determined by chip ratings and creep back at the scribe line, were determined after gravel contact.

Fig. 3.1 Prototypical seepage of an automobile fuel tank

An aggressive gasoline was built in deep drawn cups with flat tops to test the internal corrosion resistance (CE10A). (Automakers' recommendations to SASFT and their prior expertise led to the selection of this fuel.) Clamping rings and an inert gasket sealed the fuel-cup assembly. To replenish contaminated ions, prevent oxygen loss, and imitate repeated fuel tank filling, the fuel was changed every four weeks. By documenting the breadth and location of rust, as well as quantitatively by weight changes and pit depths, the extent of corrosion was assessed.

4. PROBLEM IDENTIFICATION

4.1 CORROSION:IS THE DETERIORATION OF A METAL AS A RESULT OF SLOW OXIDATION

With the abnormality of gold all metal elements are found as compounds rather than on their own. This is because most metals as oxidized by their Automotive environment.

Metals like zinc, copper and aluminum form protective coating when they oxidized

Copper forms a green tough protective layer. Iron on the other hand forms rust is porous and flakes off of the iron exposing a new layer of iron, which causes further rusting, In a galvanic cell, where the anode and cathode are located at various locations on the same metal surface, the metal is corroding. Electrons can shine from the anode to the cathode because metal is a conducting substance. The anode is located where there are more impurities in the metal. The presence of moisture and oxygen causes the electrons to be released.

Figure 4.1 The Degradation of a Metal – Automobile Fuel tank

4.2 CAUSES OF FUEL TANK RUST

Water is a necessary reactant for corrosion to take place. The electrolyte in road salt raises the water's conductivity. The salt also aids in charge neutralization, creating an environment very similar to that of the salt bridge. As a result of losing electrons to the less reactive metal, the more reactive metal oxidizes. Bending shaping or cutting metals can stress the metal. This would then become a corrosion site.

Hydrocarbon impermeability makes it the ideal material for PZEV applications. In terms of cost, comparable to those of the co-extruded blow-molded plastic fuel tanks that are now in use. Road environments-resistant to corrosion. Suitable for all fuels. Decent design adaptability. Readily producible using tried-and-true, traditional, affordable, and broadly accessible methods. Over a century of performance and safety history. Totally recyclable the annual recycling of steel from autos is close to 15 million tons. Steel gasoline tanks are not indestructible structures. They have to put up with ongoing corrosion brought on by stored products and the external atmosphere, which reduces the construction's thickness and harms its overall integrity. The detrimental effects of foundation geometrical deviation must be recorded by qualified individuals. Correct tank analysis and expert repair reduce the chance of accidents and environmental damage and extend the time they can be used.

5. EXPERIMENTAL SETUP

The experimental setup parameters needed for the fuel tank with empty area's data were obtained from journals that were cited by fuel tank with empty systems and have shown promise in helping vehicles meet pollution regulations. Inlet diffuser is among the fuel tank's most crucial components. The distribution flow at the Internals' entrance face is significantly impacted by the input diffuser. Maldistribution flow is one of the most significant issues that can arise in the fuel tank. Because of the non-uniform entrance velocity distribution flow caused by large diffuser cone angles, the turbulent exhaust gas flow from the exhaust pipe into the diffuser tends to detach from the walls and enter the internal channels [1].

As a result, the majority of the exhaust flow permit through the center of the Internal at a crucially higher velocity than in the perfect form. In a perfect converter, the flow that emerges from the intake diffuser would be consistent throughout, meaning that it would be dispersed evenly throughout all of the internal channels. The geometry of a particular design of an intake diffuser, as seen in drawings and modelled in computer programmers, is what decides how the flow is distributed across the internal frontal area. We begin by performing numerical analyses of models used in experiments. The data's collected include,

1. Transformation of data in inches to metrics.
2. Dimensions for a full flow setup.
3. Reengineering the scaling measure.

5.1 PRODUCT SIZE AFTER COMPLETE ASSEMBLY

The parameters and their descriptions are listed below.

Table 5.1 Fuel tank design specifications

Description	Details	Units
Wash coat	45	gr/m^2
Precious metals	Mild Steel	---
Channel density	200-400	$channel/cm^2$
Surface area	2.41	m^2

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Length	900	mm
Diameter	265	mm

The width of the flow channel, the depth of the fuel tank, and other design parameters are all gleaned from the assembled system.

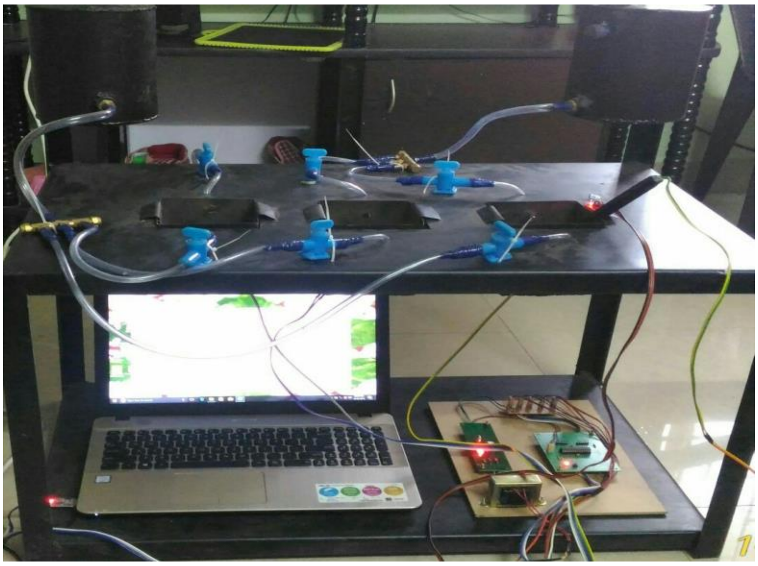

Figure 5.1 Fuel tank original design schematic – Test station

The engine was connected to a swirl Current dynamometer in order to conduct experimental tests. The goal of the test bed is to simulate realistic vehicle operating conditions. To generate air flow over a moving vehicle, two axial fans with ducting were used, as shown in Fig. 7.2 L-4, SI type, 1.3 litres engine with multi-point fuel injection (MPFI). The Fuel tank was a 3-way Fuel tank model, the properties of which are summarised in Table 7.1. The experiment used Ni-Cr thermocouples with a thickness of 1 mm. Several thermocouples protruded 5 mm from the channels to measure the temperature of the inflow gas. They were found at r coordinates of 0.2R, 0.5R, and 1R along the radial direction. A digital differential pressure transducer with a diaphragm sensor calibrated between 0 and 50 mbar was used. The velocity of the exhaust gas was measured using a vane. The Eddy Current dynamometer was used to measure torque and engine speed. Conversion efficiency was calculated by measuring the number of pollutants absorbed before and after the fuel tank using an AVL model 4000 gas analyzer at varying loads and speeds. Thermocouples, a differential pressure transducer, and a gas analyser are shown in a simplified configuration in Figure 7.2.

It is a methodical approach to determining the best possible outcomes from a set of possible values. It has played an important role in accelerating technological progress in all fields in recent years. At each level of the selection process, this method improves the method of selecting parameters. It helps the auto industry make better use of the wide variety of materials and geometrical structures at their disposal.

5.2 Bio fuel Material enhancement

The primary focus is on using the material's performance characteristics to determine which one is the greatest fit for a given task. In order to get the results, you want from your project, material choice is of the utmost importance. In order to attain these lower emission values, laminating materials are utilized to absorb carbon particles within the fuel tank.

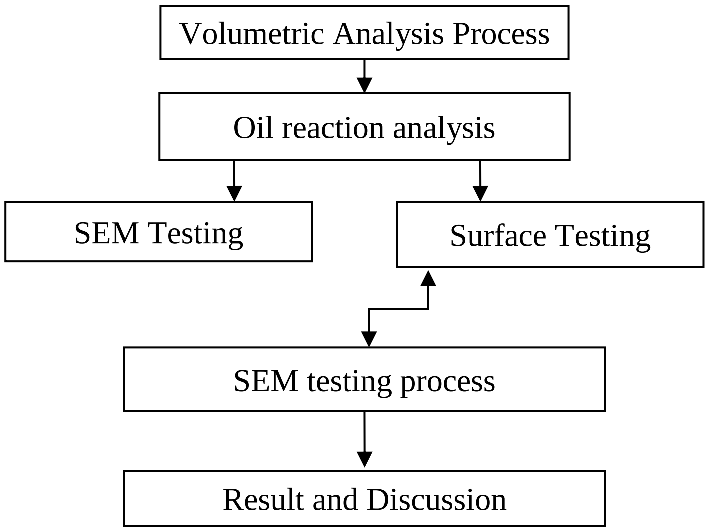

Fig. 5.2 Experimental Flow

An alternative to the traditional light microscope is the Scanning Electron Microscope (SEM). Compared to a light microscope, a scanning electron microscope (SEM) offers many benefits. Because of the SEM's deep depth of field, a sizable section of the sample can be in sharp focus at the same time. The SEM's high-resolution pictures also facilitate the detailed inspection of small, closely-spaced structures. The preparation of samples for most SEMs is straightforward because only conductive samples are required. Given its increased magnification, better depth of focus, higher resolution, and simplicity of sample observation, the SEM has become one of the most extensively utilized devices in modern research. An EDX (Energy Dispersive X-ray analysis) equipment can be added to a scanning electron microscope (SEM) in order to do compositional analysis on samples. The energy dispersive X-ray spectroscopy (EDX) method can be used to determine the composition of a specimen's surface and to make relative concentration estimates of any pollutants present.

We should have a basic understanding of how SEM works and how it is used after this lab session. Then we must practice image acquisition using the two basic imaging modes of SEM, SEI and BEI, respectively.

6. RESULTS AND DISCUSSION

6.1 EXPERIMENTATION ANALYSIS

Exhaust The speed of the air was measured by the velocity of the air. We were able to gauge both engine speed and torque with the help of the Eddy Current Sensor. Before and after the fuel tank, a STI model 2000 Biofuel analyzer measured Hight concentrations to evaluate conversion performance over a range of engine loads and speeds.

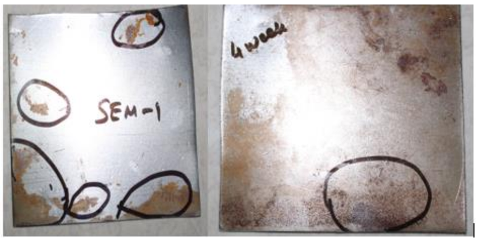

Figure 6.1 Experimentation Analysis Visual Effects

As shown in table 10 and figure 7, a schematic installation of thermocouples and a differential pressure transducer was used to measure corrosion.

Table 6.1 Experimentation Analysis

Solution ID#	Mass Change at 1 Month(g)	Mass Change at 2 Months(g)	Mass Change at 3 Months(g)
STI-1	-0.1014 ± 0.0919	-0.0280 ± 0.0045	-0.0353 ± 0.0077
STI-2	0.0053 ± 0.0026	-0.0059 ± 0.0173	0.0091 ± 0.0007
STI-3	-0.0144 ± 0.0697	0.0131 ± 0.0099	0.0138 ± 0.0117
STI-4	0.0067 ± 0.0458	-0.0480 ± 0.0835	-0.0084 ± 0.0235
STI-5	-0.0227 ± 0.0309	-0.00175 ± 0.0008	-0.0005 ± 0.0008
STI-6	0.0072 ± 0.0044	-0.0126 ± 0.0556	-0.0455 ± 0.0612
STI-7	0.0013 ± 0.0047	0.0063 ± 0.0090	0.0054 ± 0.0094
STI-8	-0.0195 ± 0.0158	0.3100 ± 0.4397	-0.0171 ± 0.0291
STI-9	-0.0075 ± 0.0025	0.0578 ± 0.0873	-0.0004 ± 0.0023
STI-10	-0.0405 ± 0.0479	-0.0429 ± 0.0532	-0.0392 ± 0.0571
STI-11	0.4078 ± 0.5791	0.0060 ± 0.0035	0.0090 ± 0.0008
STI-12	-0.0048 ± $7.07X10^{-5}$	0.0037 ± 0.0041	0.0057 ± 0.0023
STI-13	-0.0029 ± 0.0031	-0.0354 ± 0.0058	-0.0342 ± 0.0016
STI-14	-0.0019 ± 0.0064	0.0024 ± 0.0002	0.0048 ± 0.0001
STI-15	-0.3216 ± 0.4890	0.0028 ± 0.0044	0.0018 ± 0.0006
STI-16	-0.0066 ± 0.0112	-0.0265 ± 0.0339	-0.0218 ± 0.0342

6.2 Scanning Electron Microscopy (SEM) -Biofuel - Pungamia B50

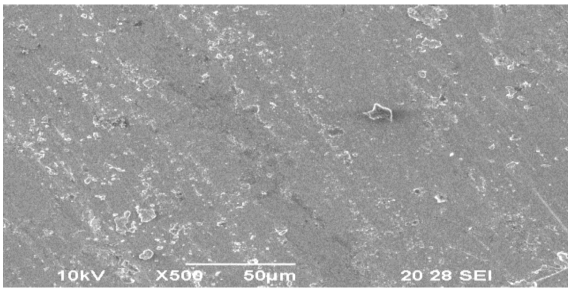

Figure 6.2 The SEM images of Brass alloy 50μm × 500

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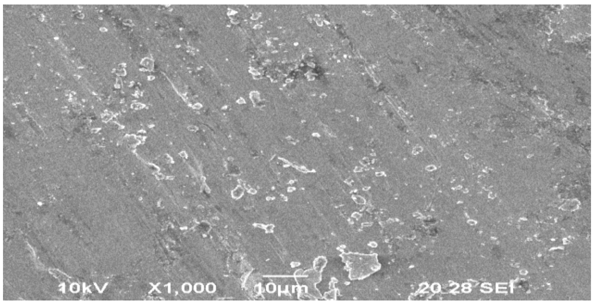

Figure 6.3 The SEM images of Brass alloy 10µm × 1000

Figures show that a fine film is visible, which reduces corrosion of the material, implying that the lubricating property of the material is increased. The MoS2 is represented by the black portions. Furthermore, the SEM image demonstrates the uniformity of the distribution.

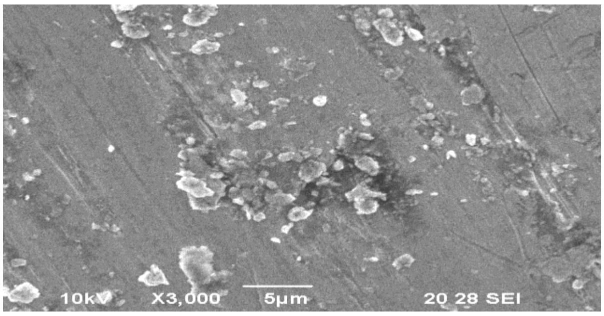

Figure 6.4 The SEM images of Brass material 5µm × 3000

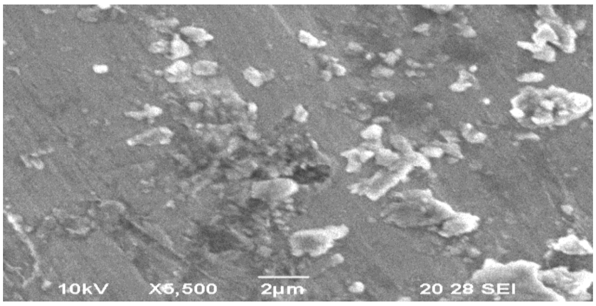

Figure 6.5 The SEM images of Brass Material 2µm × 5500

The image depicts the unevenness of the specimen, as evidenced by the white patches visible here and there. The hard particles in the SEM create voids, which are visible in the image.

7. CONCLUSION

Internal corrosion was reinforced with B50 pugamia material in the Mildsteel. Sic will help to strengthen the Biodiesel matrix. Mechanical properties such as hardness and tensile strength were tested on the developed Future material. They are also tested for adhesive wear with a plate and various corrosion resistance apparatus. SEM and numerical analysis were used to characterize the developed Mild steel material with corrosion without corrosion resistance. When compared to base Mild steel Material bonding, reinforcement improves Mild steel material hardness by 15%. From the results of the SEM images, it confirms that the presence of reinforcement and uniform distribution. Finally, we compare the numerical results of using bonded material causes in better performance analysis in Aluminum at room temperature, perfectly bonded under varying loads, with those of using the same amount of old cause material in an aluminum alloy but without a coating. in the process of spontaneous heat transfer.

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