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ASSESSMENT OF SURFACE PROPERTIES IN TESTING MODERN AUTOMOTIVE MATERIALS

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Abstract

Modern automotive engineering increasingly relies on advanced materials that combine low weight, high strength, corrosion resistance, wear resistance, manufacturability, and long-term operational stability. Advanced high-strength steels, aluminum alloys, magnesium alloys, polymer composites, and carbon-fiber-reinforced materials are widely considered important material groups for modern vehicle structures, powertrain components, chassis elements, and exterior body parts. However, the performance of these materials in real vehicle operation depends not only on their bulk mechanical properties, but also on their surface properties. Surface roughness, microhardness, friction behavior, wear resistance, coating adhesion, corrosion resistance, and surface defect condition directly influence durability, fatigue life, paint quality, sealing performance, joining quality, and tribological efficiency.

Keywords: automotive materials, surface properties, surface roughness, microhardness, wear testing, corrosion resistance, coating, tribology, lightweight materials, surface engineering.

1. Introduction

The development of modern vehicles is closely connected with the use of new materials and advanced manufacturing technologies. Automotive manufacturers aim to reduce vehicle weight, increase fuel efficiency, improve crash safety, reduce emissions, enhance durability, and lower production cost. For this reason, conventional low-carbon steels are increasingly used together with advanced high-strength steels, aluminum alloys, magnesium alloys, polymer composites, and carbon-fiber-reinforced materials. Reviews on automotive lightweight materials show that light alloys, high-strength steels, composites, and advanced materials are among the key material groups for next-generation vehicles.

Advanced high-strength steels are widely used in automotive body structures because they provide high strength and formability while supporting mass reduction and crash performance. Oak Ridge National Laboratory describes advanced high-strength steels as materials that help engineers meet safety, efficiency, emissions, manufacturability, durability, and quality requirements at relatively low cost. Aluminum and magnesium alloys are important for lightweighting because of their low density and good specific strength, while polymer composites and carbon-fiber-reinforced materials are applied where a high strength-to-weight ratio and corrosion resistance are required.

However, material selection in automotive engineering cannot be based only on tensile strength, density, or elastic modulus. In many vehicle components, the surface layer is the first zone that interacts with the environment, lubricant, paint, adhesive, seal, friction pair, road particles, moisture, salt, and temperature variation. Therefore, the surface condition often determines whether a material will perform reliably during service. For example, the surface roughness of a body panel influences paint adhesion and visual appearance. The surface hardness of a shaft, gear, brake component, or sliding contact part influences wear resistance. The surface condition of aluminum and magnesium alloys affects corrosion resistance. The surface of composite parts influences bonding, coating, and environmental durability.

The purpose of this article is to analyze the main methods used to assess surface properties of modern automotive materials and to explain their practical importance for automotive engineering. The study focuses on surface roughness, microhardness, wear resistance, and corrosion resistance. The article also presents simulated graphical results that can be used in a diploma project to illustrate how surface finishing, surface treatment, coating, and surface texturing may influence material performance.

2. Literature Review

The study of modern automotive materials includes both bulk material properties and surface characteristics. Bulk properties include tensile strength, yield strength, elongation, density, modulus of elasticity, impact resistance, and fatigue strength. Surface properties include roughness, hardness, wettability, coating adhesion, friction coefficient, wear rate, corrosion resistance, and surface defect density. In many automotive applications, surface characteristics are as important as bulk mechanical properties because failure often begins at or near the surface. A broad review of advanced lightweight materials for automobiles identifies light alloys, high-strength steels, composites, and advanced material systems as important solutions for next-generation automotive structures. Taub and Luo also note that advanced high-strength steels, aluminum and magnesium alloys, and carbon-fiber-reinforced polymers have emerged as important materials for automotive lightweighting. These material groups differ strongly in density, strength, corrosion behavior, thermal conductivity, surface treatment options, and manufacturing routes. Therefore, one universal surface testing method is not sufficient for all of them.

Surface roughness is one of the most commonly measured surface parameters. It describes the small-scale irregularities of a surface profile and is commonly expressed using parameters such as Ra, Rq, Rz, and Rt. The Surface Metrology Guide explains that roughness parameters have historically been defined in ISO 4287, while new drawings and surface texture tolerances should now refer to ISO 21920-2 because ISO 4287 has been withdrawn. This is important for diploma and engineering work because the correct standard reference must be selected when documenting roughness measurements.

In automotive manufacturing, surface roughness affects friction, lubrication, coating adhesion, paint quality, sealing, and fatigue behavior. A surface that is too rough may increase friction and wear. A surface that is too smooth may reduce mechanical interlocking for coatings or adhesives. Therefore, surface roughness must be optimized according to component function. For example, a decorative body panel requires a smooth surface for painting, while a lubricated sliding surface may need a controlled texture to retain lubricant.

Hardness testing is another key method in surface property assessment. Surface hardness is especially important for gears, shafts, bearings, brake components, engine parts, forming tools, and wear-resistant coatings. ASTM E384 covers microindentation hardness testing using Knoop and Vickers indenters under low test forces from 9.8×10^{-3} N to 9.8 N. Microhardness testing is suitable for thin coatings, heat-treated layers, nitrided zones, carburized surfaces, and small material regions where conventional macro-hardness testing is not appropriate.

The literature shows that surface property testing must be multidimensional. Roughness testing alone cannot predict wear resistance. Hardness testing alone cannot predict corrosion behavior. Salt spray testing alone cannot fully predict real outdoor durability. Therefore, a reliable assessment of modern automotive materials must combine several methods and interpret results according to the actual function of the component.

3. Materials and Methods

This article uses an analytical and simulation-based methodology. The study does not present experimental laboratory data from a specific testing machine. Instead, it summarizes surface property testing methods and provides simulated comparative graphs to demonstrate typical engineering relationships. Such a method is suitable for a diploma project because it connects theory, testing standards, and practical automotive material evaluation. The object of study is the surface property assessment of modern automotive materials. Four representative material groups are considered: advanced high-strength steel, aluminum alloy, magnesium alloy, and carbon-fiber-reinforced polymer composite. These materials were selected because they are widely discussed in the context of lightweight vehicle design and advanced automotive manufacturing. The first evaluated parameter is surface roughness. In a real laboratory, surface roughness may be measured using a contact stylus profilometer, optical profilometer, confocal microscope, or 3D surface measurement system. The parameter Ra is often used as a basic indicator of average roughness, although it does not describe all surface features. Rz, Rq, skewness, kurtosis, and 3D surface parameters may be needed for a more complete evaluation. In this article, simulated Ra values are used to compare as-machined, polished, and coated surface conditions.The second evaluated parameter is surface microhardness. In real testing, microhardness can be measured using Vickers or Knoop indentation. ASTM E384 is relevant for microindentation testing because it covers the determination of microindentation hardness of materials and includes discussion of error sources, repeatability, and reproducibility. In this article, simulated Vickers hardness values are used to compare untreated substrate surfaces and surface-treated or coated layers.

The third evaluated parameter is wear resistance. In real conditions, wear can be evaluated using pin-on-disk, block-on-ring, reciprocating sliding, abrasive wear, or component-level tests. ASTM G99 is relevant because it defines a laboratory method for wear testing using a pin-on-disk apparatus under nominally non-abrasive conditions. In this article, simulated cumulative wear mass loss is plotted against sliding distance for untreated, coated, and textured-coated surfaces.

For graphical analysis, three simulated figures were prepared. The first figure presents average surface roughness values for four automotive material groups under three surface states. The second figure compares the microhardness of untreated and treated surfaces. The third figure shows cumulative wear mass loss as a function of sliding distance. These figures are intended for educational and comparative analysis. They should not be interpreted as exact experimental results from a specific vehicle material or laboratory machine.

4. Results

4.1. Simulated Surface Roughness of Modern Automotive Materials

The first simulated result concerns surface roughness. Surface roughness is important because it affects paint quality, adhesive bonding, sealing, friction, wear, and corrosion behavior. In the simulation, four modern automotive material groups were compared: advanced high-strength steel, aluminum alloy, magnesium alloy, and carbon-fiber-reinforced polymer composite. Three surface conditions were considered: as-machined surface, polished or finished surface, and protective coated surface.

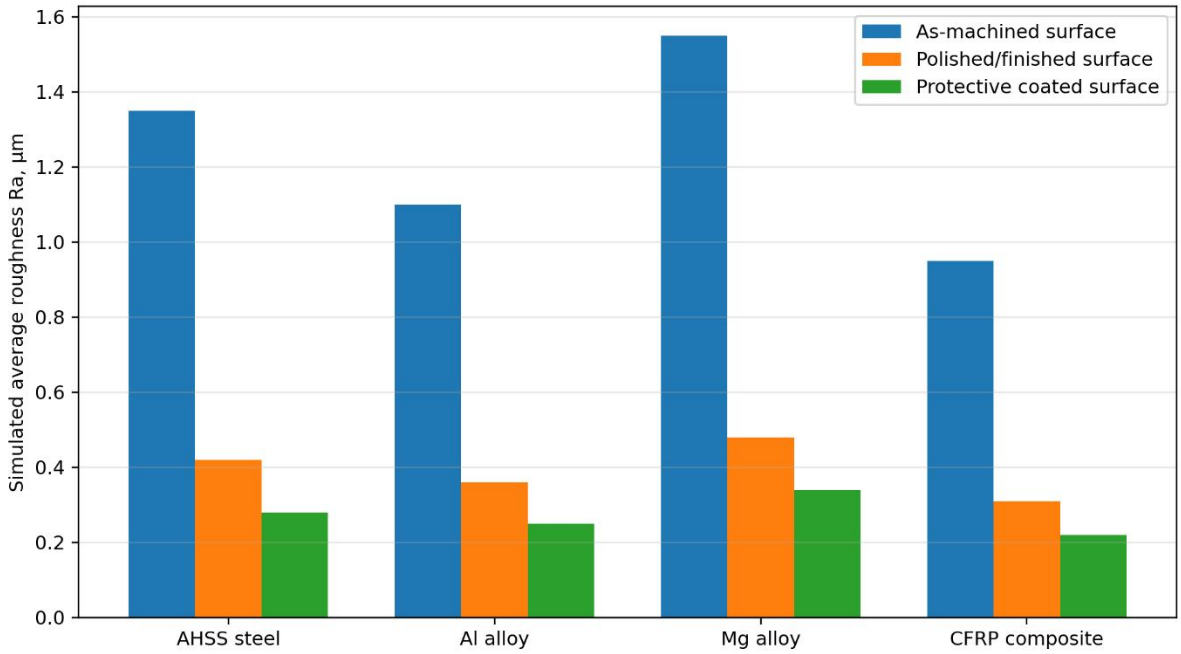

Figure 1. Simulated surface roughness of modern automotive materials.

The graph shows that as-machined surfaces have the highest average roughness. Magnesium alloy shows the highest simulated Ra value among the selected materials because magnesium components often require careful surface preparation due to oxidation and corrosion sensitivity. Aluminum alloy and advanced high-strength steel show moderate simulated roughness, while carbon-fiber-reinforced polymer composite shows relatively lower roughness in the simulated comparison.

After polishing or finishing, the roughness values decrease significantly for all materials. This indicates that mechanical finishing is effective for reducing surface irregularities. After protective coating, the roughness values decrease further. This simulated trend reflects the practical idea that coating and finishing can improve the surface quality of automotive parts. However, a lower Ra value is not always automatically better. For adhesive bonding or coating adhesion, a controlled roughness may be required to increase mechanical interlocking.

The result confirms that surface roughness must be evaluated according to component function. For visible body panels, low roughness supports better paint appearance. For sliding surfaces, the roughness must be optimized for lubrication and friction. For adhesive bonding, surface texture and surface energy must be suitable for joint strength. Therefore, roughness testing should not be limited to a single Ra value; it should be combined with functional analysis.

4.2. Simulated Microhardness Improvement After Surface Treatment

The second simulated result concerns microhardness. Surface microhardness is an important indicator of resistance to indentation, local plastic deformation, scratching, and abrasive wear. In the simulation, three metallic automotive materials were compared: advanced high-strength steel, aluminum alloy, and magnesium alloy. For each material, untreated substrate hardness and surface-treated or coated hardness were compared.

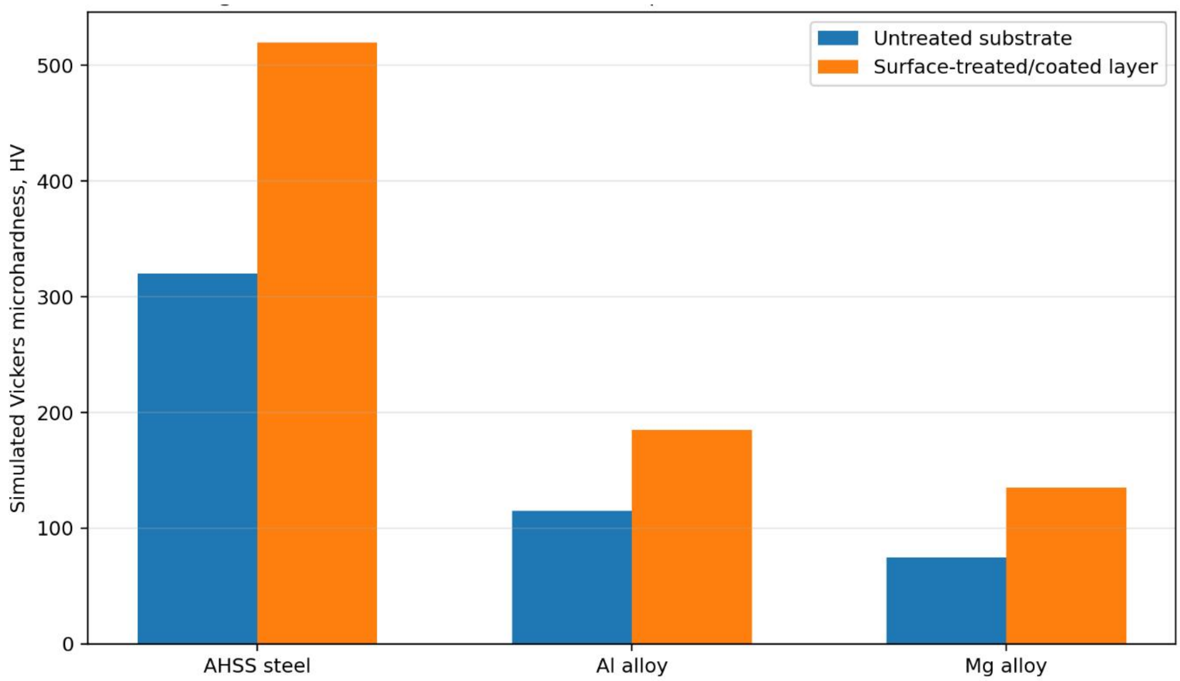

Figure 2. Simulated microhardness improvement after surface treatment.

The graph shows that surface treatment or coating increases the simulated microhardness of all three materials. Advanced high-strength steel has the highest hardness both before and after treatment. Aluminum alloy shows moderate hardness improvement, while magnesium alloy remains the softest but still benefits from surface treatment. This result reflects a general engineering principle: surface hardening and protective coating can improve wear resistance without replacing the base material.

For automotive applications, this is very important. Lightweight materials such as aluminum and magnesium can reduce vehicle mass, but their surface hardness and wear behavior may be weaker than steel in some applications. Surface treatment can compensate for this weakness. For example, anodizing, hard coating, thermal spraying, nitriding, physical vapor deposition, and conversion coatings can improve surface performance depending on the material and component function.

Microhardness testing is especially useful for thin surface layers because conventional hardness tests may be too deep or too large for coatings. ASTM E384 is relevant because it covers microindentation tests using Knoop and Vickers indenters under low loads. Therefore, microhardness measurement should be included in automotive material testing when surface treatment or coating is applied.

4.3. Simulated Wear Resistance Under Sliding Contact

The third simulated result concerns wear resistance. Wear is one of the most important surface-related failure mechanisms in automotive components. It occurs in gears, shafts, bearings, brake systems, clutch systems, piston rings, valve train elements, suspension joints, and many other contact pairs. The simulation compares cumulative wear mass loss for three surface conditions: untreated metallic surface, hard protective coating, and textured plus coated surface.

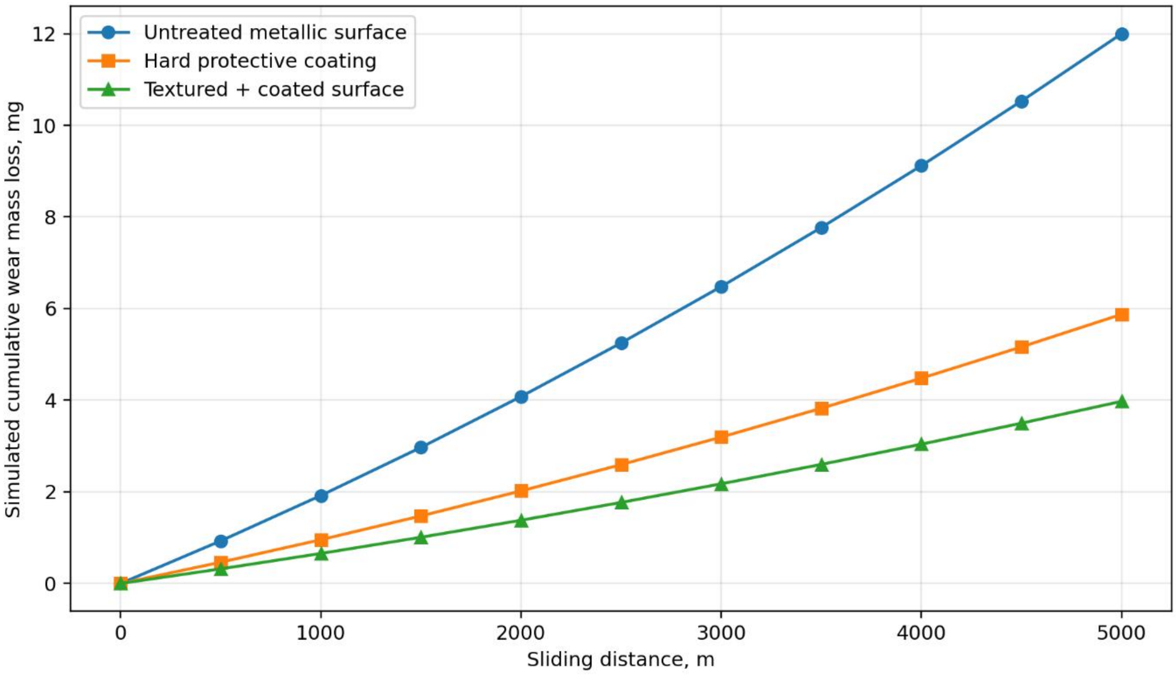

Figure 3. Simulated wear resistance under pin-on-disk type sliding.

Open Figure 3

The graph shows that the untreated metallic surface has the highest simulated cumulative wear loss. The hard protective coating reduces wear significantly. The textured plus coated surface shows the lowest simulated wear. This trend demonstrates the potential benefit of combining coating and surface texturing. Surface texturing can create micro-reservoirs for lubricant, trap wear particles, reduce real contact area, and improve friction conditions. A review of wear reduction techniques also identifies surface texturing as one of the approaches used to reduce wear.

The pin-on-disk concept is useful for comparing material pairs under controlled conditions. ASTM G99 covers laboratory wear testing using a pin-on-disk apparatus and can also be used to determine friction coefficient. However, wear results must be interpreted carefully. A material that performs well in a laboratory pin-on-disk test may not necessarily perform equally well in a real vehicle component if lubrication, temperature, vibration, contamination, or contact geometry differs.

The simulated wear graph confirms that surface quality and surface modification are essential for automotive durability. Hardness alone is not enough. A very hard coating may fail if adhesion is poor or if the substrate is too soft. A smooth surface may wear quickly if lubrication is poor. A textured surface may be beneficial under lubricated sliding but harmful under some dry conditions. Therefore, wear testing should be performed under conditions that represent the intended component operation.

5. Conclusion

Modern automotive materials are selected not only for their strength, density, and cost, but also for their surface performance. The surface layer of a vehicle component interacts with the environment, friction pairs, coatings, adhesives, seals, lubricants, and mechanical loads. Therefore, surface properties must be tested and evaluated as a key part of automotive material qualification.

This article analyzed the assessment of surface properties in testing modern automotive materials. The study focused on surface roughness, microhardness, wear resistance, coating performance, and corrosion resistance. Advanced high-strength steel, aluminum alloy, magnesium alloy, and carbon-fiber-reinforced polymer composite were considered as representative modern automotive materials.

The first simulated graph showed that machining, finishing, and coating significantly influence average surface roughness. The second graph showed that surface treatment and coating can increase microhardness, especially for metallic materials. The third graph demonstrated that coating and surface texturing can reduce cumulative wear mass loss under sliding contact. These results confirm that surface modification is an effective way to improve automotive material durability.

The article also showed that surface testing must be multidimensional. Roughness measurement alone is not enough to predict durability. Microhardness alone does not describe corrosion resistance. Pin-on-disk wear testing gives useful comparative data but must be interpreted according to real operating conditions. Salt spray testing is useful for corrosion comparison, but its results should not be used as the only prediction of natural environmental performance.

For diploma project application, a practical testing algorithm was proposed. It includes material selection, specimen preparation, roughness measurement, microhardness testing, wear testing, corrosion testing, and integrated data analysis. This approach allows the researcher to evaluate the surface properties of modern automotive materials in a scientifically justified and practically useful way.

In conclusion, the durability and reliability of modern automotive materials depend strongly on surface quality. Proper surface finishing, suitable coating, controlled roughness, improved microhardness, optimized surface texture, and corrosion protection can significantly improve the service life of automotive components. Therefore, the assessment of surface properties should be considered an essential part of modern automotive material testing.

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