PROFESSIONAL TECHNICIAN SERIES

Part of Pearson Automotive’s Professional Technician Series, the seventh edition of Automotive Chassis Systems represents the future of automotive textbooks. The series is a full-color, media-integrated solution for today’s students and instructors. The series includes textbooks that cover all eight areas of ASE certification, plus additional titles covering common courses.

The series is also peer reviewed for technical accuracy.

NEW TO THIS SEVENTH EDITION

As a result of comments and suggestions from reviewers and automotive instructors, the following changes have been made to the new 7th edition:

- Over 50 new full color photos and line drawings have been added to help bring the subject to life.
- All of the content throughout has been updated to meet the latest NATEF and ASE standards.
- The chapter on brake principles (Chapter 4) has been expanded and now includes the details on brake friction materials which are now in one location instead of being repeated in the drum and disc brake chapters.
- Qualifying a brake lathe information added to chapter 14.
- The chapter on regenerative brakes (chapter 20) has been moved as suggested by automotive instructors.
- The chapter on power steering has been split into two separate chapters - Hydraulic Power Steering Systems (chapter 30) and Electric Power Steering Systems (chapter 31) making teaching and learning these topics easier.
- New Case Study elements which include the “Three Cs” (Complaint, Cause and Correction) added to many chapters.
- New content on tire selection, chrome clad wheels and using a pin plate to balance wheels added in chapter 23.
- Additional content on snap-in and clamp-on TPMS sensors plus updated relearn procedures in chapter 4.
- Additional content on various wheel weight material plus wheel flange information added to the totally updated Chapter 23.
- New information a Hi Per strut included in Chapter 25.
- Many new review and chapter quiz questions where changed to match the new and updated content in each chapter.

Examples of what was changed and updated include:

1. The GM regular production code (RPO) information added to chapter 3 (Braking System Components and Performance Standards)
2. Ceramic brake pads and environmental concerns of copper in brake friction material added to chapter 4 (Brake Principles and Friction Materials).
3. Case studies have been updated to include the “Three Cs” (complaint, cause and correction).
4. The BCM control of the red brake warning light (RBWL) has been added to chapter 6.
5. Brake line corrosion reduction coating has been added to chapter 7 (Brake Fluid and Lines).
6. New disc brake photo sequence added to chapter 13 (Disc Brake Diagnosis and Service)

ASE AND NATEF CORRELATED

NATEF certified programs need to demonstrate that they use course material that covers NATEF and ASE tasks. All Professional Technician textbooks have been correlated to the appropriate ASE and NATEF task lists. These correlations can be found in the appendices.

A COMPLETE INSTRUCTOR AND STUDENT SUPPLEMENTS PACKAGE

All Professional Technician textbooks are accompanied by a full set of instructor and student supplements. Please see page vi for a detailed list of supplements.

A FOCUS ON DIAGNOSIS AND PROBLEM SOLVING

The Professional Technician Series has been developed to satisfy the need for a greater emphasis on problem diagnosis. Automotive instructors and service managers agree that students and beginning technicians need more training in diagnostic procedures and skill development. To meet this need and demonstrate how real-world problems are solved, Case Study features are included throughout and highlight how real-life problems are diagnosed and repaired.

The following pages highlight the unique core features that set the Professional Technician Series book apart from other automotive textbooks.
**Learning Objectives and Key Terms**

appear at the beginning of each chapter to help students and instructors focus on the most important material in each chapter. The chapter objectives are based on specific ASE and NATEF tasks.

**Tech Tips**

feature real-world advice and “tricks of the trade” from ASE-certified master technicians.

**SAFETY TIP**

Always dispose of oily shop cloths in an enclosed container to prevent a fire. [SEE FIGURE 1–69.]

Whenever oily cloths are thrown together on the floor or workbench, a chemical reaction can occur, which can ignite the cloth even without an open flame. This process of ignition without an open flame is called spontaneous combustion.

**Case Study**

Three Brake Jobs in 40,000 Miles

A service technician was asked to replace the front disc brake pads on a Pontiac Grand Am because the sensors were touching the rotors and making a squealing sound. This was the third time that the front brakes needed to be replaced. Previous brake repairs had been limited to replacement of the front disc brake pads only.

When the caliper was removed and the pads inspected, it was discovered that a part of one pad had broken and a piece of the lining was missing. [SEE FIGURE 13–15.]

**Frequently Asked Questions**

How Many Types of Screw Heads Are Used in Automotive Applications?

There are many, including Torx, hex (also called Allen), plus many others used in custom vans and motor homes. [SEE FIGURE 1–9.]

**Frequently Asked Questions**

are based on the author’s own experience and provide answers to many of the most common questions asked by students and beginning service technicians.
NOTE: Most of these “locking nuts” are grouped together and are commonly referred to as prevailing torque nuts. This means that the nut will hold its tightness or torque and not loosen with movement or vibration.

NOTES provide students with additional technical information to give them a greater understanding of a specific task or procedure.

CAUTION: Never use hardware store (nongraded) bolts, studs, or nuts on any vehicle steering, suspension, or brake component. Always use the exact size and grade of hardware that is specified and used by the vehicle manufacturer.

CAUTIONS alert students about potential damage to the vehicle that can occur during a specific task or service procedure.

WARNING

Do not use incandescent trouble lights around gasoline or other flammable liquids. The liquids can cause the bulb to break and the hot filament can ignite the flammable liquid which can cause personal injury or even death.

WARNINGS alert students to potential dangers to themselves during a specific task or service procedure.

<table>
<thead>
<tr>
<th>WARNING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not use incandescent trouble lights around gasoline or other flammable liquids. The liquids can cause the bulb to break and the hot filament can ignite the flammable liquid which can cause personal injury or even death.</td>
</tr>
</tbody>
</table>

THE SUMMARY, REVIEW QUESTIONS, AND CHAPTER QUIZ at the end of each chapter help students review the material presented in the chapter and test themselves to see how much they’ve learned.

THE SUMMARY

1. Bolts, screws, and nuts are commonly used as fasteners in the repair and service of vehicles. They are assembled to keep parts from coming apart. Preventive maintenance is performed to keep the parts from coming apart.
2. Preventative maintenance involves the outer body of the vehicle, the engine, and the transmission of the vehicle. Preventative maintenance ensures the vehicle is kept running safely and efficiently.
3. Various maintenance services, such as oil changes and filter changes, are required to keep the vehicle running. Preventative maintenance services are performed to keep the vehicle running efficiently and safely.
4. A drive belt is used to control the speed of the engine. Preventative maintenance services are performed to keep the drive belt running smoothly and efficiently.
5. Various maintenance services, such as oil changes and filter changes, are required to keep the vehicle running. Preventative maintenance services are performed to keep the drive belt running smoothly and efficiently.
6. Various maintenance services, such as oil changes and filter changes, are required to keep the vehicle running. Preventative maintenance services are performed to keep the drive belt running smoothly and efficiently.

REVIEW QUESTIONS

1. Identify the type of fastener that is used to secure the vehicle’s undercarriage. A. Drive belt B. Drive belt C. Drive belt D. Drive belt
2. The vehicle’s undercarriage is assembled to keep parts from coming apart. Preventative maintenance services are required to keep the vehicle running. Preventative maintenance services are performed to keep the vehicle running efficiently and safely.
3. Sealant is used to prevent the vehicle’s undercarriage from becoming damaged. Preventative maintenance services are performed to keep the vehicle running efficiently and safely.
4. Sealant is used to prevent the vehicle’s undercarriage from becoming damaged. Preventative maintenance services are performed to keep the vehicle running efficiently and safely.
5. Sealant is used to prevent the vehicle’s undercarriage from becoming damaged. Preventative maintenance services are performed to keep the vehicle running efficiently and safely.

CHAPTER QUIZ

1. What type of fastener is used to secure the vehicle’s undercarriage? A. Drive belt B. Drive belt C. Drive belt D. Drive belt
2. The vehicle’s undercarriage is assembled to keep parts from coming apart. Preventative maintenance services are required to keep the vehicle running. Preventative maintenance services are performed to keep the vehicle running efficiently and safely.
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STEAD-BY-STEP photo sequences show in detail the steps involved in performing a specific task or service procedure.
# SUPPLEMENTS

## RESOURCES IN PRINT AND ONLINE

<table>
<thead>
<tr>
<th>NAME OF SUPPLEMENT</th>
<th>PRINT</th>
<th>ONLINE</th>
<th>AUDIENCE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor Resource Manual 0134072480</td>
<td>✔️</td>
<td></td>
<td>Instructors</td>
<td>NEW! The ultimate teaching aid: chapter summaries, key terms, chapter learning objectives, lecture resources discuss/demonstrate classroom activities. MyAutomotiveLab correlation, and answers to the in-text review and quiz questions.</td>
</tr>
<tr>
<td>TestGen 0134072502</td>
<td>✔️</td>
<td></td>
<td>Instructors</td>
<td>Test generation software and test bank for the text.</td>
</tr>
<tr>
<td>PowerPoint Presentation 0134072448</td>
<td>✔️</td>
<td></td>
<td>Instructors</td>
<td>Slides include chapter learning objectives, lecture outline of the text, and graphics from the book.</td>
</tr>
<tr>
<td>Image Bank 0134072456</td>
<td>✔️</td>
<td></td>
<td>Instructors</td>
<td>All of the images and graphs from the textbook to create customized lecture slides.</td>
</tr>
<tr>
<td>NATEF Correlated Task Sheets – for instructors</td>
<td>✔️</td>
<td></td>
<td>Instructors</td>
<td>Downloadable NATEF task sheets for easy customization and development of unique task sheets.</td>
</tr>
<tr>
<td>NATEF Correlated Task Sheets – for students 0134072375</td>
<td>✔️</td>
<td></td>
<td>Students</td>
<td>Study activity manual that correlates NATEF Automobile Standards to chapters and page numbers in the text. Available to students at a discounted price when packaged with the text.</td>
</tr>
</tbody>
</table>

All online resources can be downloaded from the Instructor's Resource Center: [www.pearsonhighered.com/irc](http://www.pearsonhighered.com/irc)
After studying this chapter, the reader will be able to:

1. Discuss the energy principles that apply to brakes.
2. Discuss the friction principles that apply to brakes.
3. Describe how brakes can fade due to excessive heat.
4. Describe how deceleration rate is measured.
5. Discuss the mechanical principles that apply to brakes.

**KEY TERMS**

- Asbestos 68
- Brake fade 66
- Ceramic 69
- Coefficient of friction 65
- Copper 70
- Edge codes 71
- Energy 63
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- Leaf mark 71
- Lining fade 66
- Mechanical fade 66
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- Non-asbestos 69
- Non-asbestos organic (NAO) 69
- Non-asbestos synthetic (NAS) 69
- Semimetallic 69
- Weight bias 64
- Work 63
ENERGY AND WORK

ENERGY  Energy is the ability to do work. There are many forms of energy, but chemical, mechanical, and electrical energy are the most familiar kinds involved in the operation of an automobile.  SEE FIGURE 4-1.

WORK  Work is the transfer of energy from one physical system to another—especially the transfer of energy to an object through the application of force. This is precisely what occurs when a vehicle’s brakes are applied: The force of the actuating system transfers the energy of the vehicle’s motion to the brake drums or rotors where friction converts it into heat energy and stops the vehicle.

KINETIC ENERGY  Kinetic energy is a fundamental form of mechanical energy. It is the energy of mass in motion. Every moving object possesses kinetic energy, and the amount of that energy is determined by the object’s mass and speed. The greater the mass of an object and the faster it moves, the more kinetic energy it possesses. Even at low speeds, a moving vehicle has enough kinetic energy to cause serious injury and damage. The purpose and function of the brake system is to dispose of that energy in a safe and controlled manner. Engineers calculate kinetic energy using the following formula:

\[ \frac{mv^2}{29.9} = E_k \]

where:
- \( m \) = mass or weight of the vehicle in pounds (lb)
- \( v \) = velocity of the vehicle in miles per hour
- \( E_k \) = kinetic energy in foot-pounds (ft-lb)

Another way to express this equation is as follows:

\[ \text{weight} \times \frac{\text{speed}^2}{29.9} = \text{kinetic energy} \]

KINETIC ENERGY EXAMPLE #1  A 3,000-lb vehicle traveling at 30 mph is compared with a 6,000-lb vehicle also traveling at 30 mph.  SEE FIGURE 4-2.

The equations for computing their respective kinetic energies look like this:

\[ \frac{3,000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90,301 \text{ ft-lb} \]
And if the speed quadruples (4), say from 15 to 60 mph, the kinetic energy becomes 16 times as great ($4^2 = 16$). This is the reason speed has such an impact on kinetic energy.

**Kinetic Energy Example #2**  A 3,000-lb vehicle traveling at 30 mph is compared with the same vehicle traveling at 60 mph.  

- When the speed of a vehicle is doubled from 15 to 60 mph, the kinetic energy becomes 16 times as great ($4^2 = 16$). This is the reason speed has such an impact on kinetic energy.

**INERTIA**

**Definition**  Inertia is defined by Isaac Newton’s first law of motion, which states that a body at rest tends to remain at rest, and a body in motion tends to remain in motion in a straight line unless acted upon by an outside force.

**Weight Transfer**  Inertia, in the form of weight transfer, plays a major part in braking performance. Newton’s first law of motion states, if applied to a vehicle:

- A moving vehicle will remain in motion unless acted upon by an outside force.

The sequence that occurs when the brakes are applied includes:

- The vehicle brakes provide that outside force, but when the brakes are applied at the wheel friction assemblies, only the wheels and tires begin to slow immediately.
- The rest of the vehicle, all of the weight carried by the suspension, attempts to remain in forward motion.
- The result is that the front suspension compresses, the rear suspension extends, and the weight is transferred toward the front of the vehicle.

**Weight Bias**  The total weight of the vehicle does not change during a brake application, only the amount supported by each axle. To compound the problem of weight transfer, most vehicles also have a forward **weight bias**, which means...
that even when stopped, more than 50% of their weight is supported by the front wheels. This occurs because the engine, transmission, and most other heavy parts are located toward the front of the vehicle. ● See Figure 4–5.

Front-wheel-drive (FWD) vehicles, in particular, have a forward weight bias. Whenever the brakes are applied, weight transfer and weight bias greatly increase the load on the front wheels, while the load on the rear wheels is reduced. This requires the front brakes to provide 60% to 80% of the total braking force. To deal with the extra load, the front brakes are much more powerful than the rear brakes.

**COEFFICIENT OF FRICTION**

**Definition** The amount of friction between two objects or surfaces is commonly expressed as a value called the coefficient of friction and is represented by the Greek letter μ, pronounced “mYOO.” The coefficient of friction, also referred to as the friction coefficient, is determined by dividing tensile force by weight force. The tensile force is the pulling force required to slide one of the surfaces across the other. The weight force is the force pushing down on the object being pulled. The complete friction assembly (including lining and backing) is often called a brake pad or brake shoe. The friction coefficient (μ) for most standard brake pads is usually in the range of 0.25 to 0.55.

**Static and Kinetic Friction** There are actually two measurements of the coefficient of friction: the static friction coefficient and the kinetic friction coefficient. The static value is the coefficient of friction with the two friction surfaces at rest. The kinetic value is the coefficient of friction while the two surfaces are sliding against one another. The coefficient of static friction is always higher than that of kinetic friction, which explains why it is harder to start an object moving than to keep it moving. ● See Figure 4–6.

It takes 100 lb of tensile force to start the wooden block sliding, but once in motion, it takes only 50 lb to keep it sliding. The relatively high static friction is harder to overcome than the somewhat lower kinetic friction. The static and kinetic friction coefficients for several combinations of materials are shown in ● Chart 4–1.

The difference between static and kinetic friction explains why parking brakes, although much less powerful than service
because as a brake rotor heats up it expands toward the brake pads rather than away from them.

**Lining fade**

Lining fade affects both drum and disc brakes and occurs when the friction material overheats to the point where its coefficient of friction drops off. **SEE FIGURE 4–7.**

When lining fade occurs on drum brakes, partial braking power can sometimes be restored by increasing pressure on the brake pedal, although this may only make matters worse since the extra pressure increases the amount of heat and fade. With disc brakes, lining fade is possible, but is less of a problem because of disc brakes’ superior ability to dissipate heat. The rotor friction surfaces are exposed to the passing air, and most rotors have internal ventilation passages that further aid in cooling.

**Gas fade**

Gas fade is a relatively rare type of brake fade that occurs under very hard braking when a thin layer of hot gases and dust particles builds up between the brake drum or rotor and linings. The gas layer acts as a lubricant and reduces friction. **SEE FIGURE 4–8.**

As with lining fade, greater application force at the brake pedal is required to maintain a constant level of stopping power.

Gas fade becomes more of a problem as the size of the brake lining increases because gases and particles have a harder time escaping from under a drum brake shoe than a disc brake pad.

Some high performance brake shoes and pads have slotted linings to provide paths for gas and particles to escape.

**Figure 4–7** Some heat increases the coefficient of friction but too much heat can cause it to drop off sharply.

**Figure 4–8** One cause of brake fade occurs when the phenolic resin, a part of the friction material, gets so hot that it vaporizes. The vaporized gas from the disc brake pads gets between the rotor (disc) and the friction pad. Because the friction pad is no longer in contact with the rotor, no additional braking force is possible.

**Brake fade**

If repeated hard stops are performed, the brake system components can overheat and lose effectiveness or possibly fail altogether. This loss of braking power is called brake fade.

**Mechanical fade**

Mechanical fade occurs when a brake drum overheats and expands away from the brake lining. To maintain braking power, the brake shoes must move farther outward, which requires additional brake pedal travel. When the drum expands to a point where there is not enough pedal travel to keep the lining in contact with the drum, brake fade occurs. Mechanical fade is not a problem with disc brakes.
Maximum deceleration rates for most vehicles and light trucks range from 16 to 32 ft/sec² (5 to 10 m/sec²). An average deceleration rate of 15 ft/sec² (3 m/sec²) can stop a vehicle traveling at 55 mph (88 km/h) in about 200 ft (61 m) in less than 4 seconds. See Figure 4–10.

**Brake Temperature** Temperatures at the front brake pads can reach:
- 1,300°F (700°C) or higher during normal driving
- as high as 1,800°F (980°C) during braking from a high speed or during long descents

Brake fluid and rubber components may reach 300°F (150°C) or higher.

**How to Reduce Possible Brake Fade** To help prevent possible brake fade while descending long hills, place the gear selector into a lower drive range such as “2” or even “1” if going slowly enough. This action allows for additional engine braking and takes the load off of the wheel brakes. See Figure 4–9.

- Maximum deceleration rates for most vehicles and light trucks range from 16 to 32 ft/sec² (5 to 10 m/sec²).
- An average deceleration rate of 15 ft/sec² (3 m/sec²) can stop a vehicle traveling at 55 mph (88 km/h) in about 200 ft (61 m) in less than 4 seconds. See Figure 4–10.

**WATER FADE** If a vehicle is driven through deep water or during a severe rainstorm, water can get between the brake drum and the linings. When this occurs, no stopping power is possible until the water is pushed out and normal friction is restored. While water fade is most likely to occur with drum brakes, it can also occur on disc brakes. After driving through deep water, the wise driver should lightly apply the brakes to check the operation and to help remove any water trapped between the friction material and the rotor or drum.

**DECELERATION RATES**

**Terminology** Deceleration rates are measured in units of “feet per second per second” (No, this is not a misprint). What it means is that the vehicle will change in velocity during a certain time interval divided by the time interval. Deceleration is abbreviated “ft/sec²” (pronounced “feet per second per second” or “feet per second squared”) or meters per sec² (m/sec²) in the metric system.

**Typical Deceleration Rates** Typical deceleration rates include the following:
- Comfortable deceleration is about 8.5 ft/sec² (3 m/sec²).
- Loose items in the vehicle will “fly” above 11 ft/sec² (3.5 m/sec²).

**Brake Friction Materials**

**Purpose and Function** Brake friction materials are composed of relatively soft but tough and heat-resistant material to provide the friction between the moveable part of the braking system (drum or rotor) and the stationary part of the braking system. The brake friction material has to provide the friction needed to slow and stop the vehicle quietly and still provide a long service life.

**Brake Liner Composition** Brake shoes and pads operate under the most extreme conditions in the entire brake system and are subject to wear. Friction materials such as
disc brake pads or drum brake shoes contain a mixture of ingredients. These materials include a binder such as:

- thermosetting resin
- fibers (for reinforcement)
- friction modifiers (to obtain a desired coefficient of friction)

**BRAKE BLOCKS** The various ingredients in brake lining are mixed and molded into the shape of the finished product. The fibers in the material are the only thing holding this mixture together. A large press is used to force the ingredients together to form a brake block, which eventually becomes the brake lining/pads.

### ASBESTOS

**DEFINITION** Asbestos is the term used to describe naturally occurring silicate minerals that consist of long fibers. Asbestos mining began more than 4,000 years ago, but did not start large scale until the end of the nineteenth century when manufacturers and builders began using asbestos for:

- sound absorption
- its resistance to fire, heat, electrical, and chemical damage
- affordability

It was used in such applications as electrical insulation for hotplate wiring and in building insulation. When asbestos is used for its resistance to fire or heat, the fibers are often mixed with cement or woven into fabric or mats. These desirable properties made asbestos a very widely used material, and its use continued to grow throughout most of the twentieth century until the carcinogenic (cancer-causing) effects of asbestos were discovered which caused its effective demise as a mainstream construction and fireproofing material in most countries.

**ASBESTOS HAZARDS** Asbestos exposure can cause scar tissue to form in the lungs. This condition is called asbestosis. It gradually causes increasing shortness of breath, and the scarring to the lungs is permanent. Even low exposures to asbestos can cause mesothelioma, a type of fatal cancer of the lining of the chest or abdominal cavity. Asbestos exposure can also increase the risk of lung cancer as well as cancer of the voice box, stomach, and large intestine. It usually takes 15 to 30 years or more for cancer or asbestos lung scarring to show up after exposure.

### TECH TIP

**Competitively Priced Brakes**

The term “competitively priced” means lower cost. Most brake manufacturers offer “premium” as well as lower-price linings to remain competitive with other manufacturers or with importers of brake lining material produced overseas by U.S. or foreign companies. Organic asbestos brake lining is inexpensive to manufacture. In fact, according to warehouse distributors and importers, the box often costs more than the brake lining inside. Professional brake service technicians should only install brake linings and pads that will give braking performance equal to that of the original factory brakes. For best results, always purchase high-quality brake parts from a known brand-name manufacturer.

### ASBESTOS BRAKE LININGS

Asbestos was a popular component for vehicle brakes because of its heat resistance and strength. Brake friction materials that used asbestos were called **organic** linings/pads. The U.S. Environmental Protection Agency (EPA) has not banned the use of asbestos in drum brake linings or disc brake pads even though it has banned its use in corrugated paper, roll board, commercial paper, specialty paper, and flooring felt.

The concentration of asbestos in brake lining was estimated at 30% to 50%. The routine tasks of “blowing out” brake surfaces (using an air hose to clean the surfaces) were considered to be the most common way workers were exposed. The use of asbestos for brake linings was never abandoned completely. *SEE CHART 4–2.*
Brake Principles and Friction Materials

These friction materials are often called ceramic in the American aftermarket because they include ceramic fibers which are usually potassium titanate.

Carbon Fiber Friction Materials

Terminology  Carbon fiber brake lining is the newest and most expensive of the lining materials.

These friction materials are often quieter than semimetallic pads and cause less wear to brake rotors as do semimetallic pads. SEE Chart 4–4.

Non-Asbestos/Ceramic Friction Materials

Terminology  Brake pads and linings that use synthetic material such as aramid fibers instead of steel are usually referred to as:

- non-asbestos
- non-asbestos organic (NAO)
- non-asbestos synthetic (NAS)

Carbon fiber material is often called CFRC (carbon fiber-reinforced carbon). It is composed of a carbon mix into which reinforcing carbon fibers are embedded. CFRC is commonly used in the brakes of jet aircraft and racing cars. CFRC brakes provide constant friction coefficient whether cold or hot, low wear rates, and low noise development.

Semimetallic Friction Materials

Definition  The term semimetallic refers to brake lining material that uses metal rather than asbestos in its formulation. It still uses resins and binders and is, therefore, not 100% metal, but rather semimetallic. Semimetallic pads are commonly called “semi-mets.”

Construction  The metal in most metallic linings is made from metal particles that have been fused together without melting. This process is called sintering and the result is called sintered metal linings. Most semimetallic linings do not contain asbestos. Semimetallic linings require a very smooth finish on the rotor because the metal in the lining does not conform to the surface of the rotor, as does asbestos lining. A major disadvantage of semimetallic disc brake pads is that it causes a lot of brake dust which discolors the vehicle wheels. SEE Chart 4–3.

Non-Asbestos Organic (NAO) Friction Materials

Chart 4–3  Typical brake compositions for semimetallic disc brake pads.

<table>
<thead>
<tr>
<th>INGREDIENT</th>
<th>FORMULA RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenolic resin</td>
<td>15–40%</td>
</tr>
<tr>
<td>Graphite or carbon particles</td>
<td>15–40%</td>
</tr>
<tr>
<td>Steel fibers</td>
<td>0–25%</td>
</tr>
<tr>
<td>Ceramic powders</td>
<td>2–10%</td>
</tr>
<tr>
<td>Steel, copper, brass metal powders</td>
<td>15–40%</td>
</tr>
<tr>
<td>Other modifiers (rubber scrap)</td>
<td>0–20%</td>
</tr>
</tbody>
</table>

These friction materials are often called ceramic in the American aftermarket because they include ceramic fibers which are usually potassium titanate.

Non-Asbestos/Synthetic (NAS) Friction Materials

Chart 4–4  Typical compositions for NAO/Ceramic friction materials.

<table>
<thead>
<tr>
<th>INGREDIENT</th>
<th>FORMULA RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenolic resin</td>
<td>15–40%</td>
</tr>
<tr>
<td>Graphite or carbon</td>
<td>20–30%</td>
</tr>
<tr>
<td>Copper</td>
<td>0–22% (Being phased out)</td>
</tr>
<tr>
<td>Ceramic powders</td>
<td>5–30%</td>
</tr>
<tr>
<td>Aluminum, barium, calcium, iron, potassium, magnesium, sodium</td>
<td>Each &lt;2%</td>
</tr>
<tr>
<td>Fillers (barium sulfate, aramid fibers, ceramic fibers, other mined mineral powders)</td>
<td>5–10%</td>
</tr>
</tbody>
</table>
What Do D3EA and BEEP Mean?

Original equipment brake pads and shoes are required to comply with the Federal Motor Vehicle Safety Standard (FMVSS) 135, which specifies maximum stopping distances. There is also a requirement for fade resistance, but no standard for noise or wear. Aftermarket (replacement) brake pads and shoes are not required to meet the FMVSS standard. However, several manufacturers of replacement brake pads and shoes are using a standardized test that closely matches the FMVSS standard and is called the “Dual Dynamometer Differential Effectiveness Analysis” or D3EA. This test is currently voluntary and linings that pass the test can have a “D3EA certified” seal placed on the product package. BEEP stands for “Brake Effectiveness Evaluation Procedure” and is a series of tests on aftermarket brake components that is similar to the FMVSS tests and SAE J2430 standards.

Environmental Concern

Tiny amounts of copper from brakes fall onto the streets and parking lots every time the brakes are used. Copper is a pollutant because:

- It is toxic to certain sensitive species of algae (phytoplankton) that form the base of the aquatic food chain.
- Copper also directly damages the sensory capabilities of salmon, making it difficult for them to avoid predators or find their way back to their spawning grounds.

Copper is not necessarily harmful to the environment because it is vital to the health of both plants and animals. Copper from brakes account for anywhere from 35% to 60% of copper in California’s urban watershed runoff. In some urban watersheds, this added copper may be enough to cause water concentrations to exceed the water quality standard for copper. This led to determining a course of action that would address the issue.

Legal Requirements to Reduce Copper

The issue of copper in the environment has been under consideration since the 1990s when cities south of San Francisco were having trouble meeting Clean Water Act (CAA) requirements to reduce copper in urban runoff flowing into San Francisco Bay. Studies indicated that brake pads were a major source of copper in that runoff. California and Washington in 2010 passed laws mandating a reduction in the amount of copper

Frequently Asked Question

What Are Ceramic Pads Exactly?

NAO/Ceramic friction materials contain some ceramic powders or fibers. They are not “ceramic matrix composites” but rather they are an organic matrix composite molded using a phenolic resin. NAO materials typically exhibit low friction and/or high wear rates at high temperatures. To counteract this behavior, they sometimes contain many other raw materials (such as abrasives and metal sulfides) to maintain thermal stability. Metal sulfides generally provide lubrication and reduce noise created by these friction materials. Ceramic compounds provide much quieter braking because the ceramic compound helps dampen noise by generating a frequency beyond the human hearing range.

Another characteristic that makes ceramic materials attractive is the absence of noticeable dust. All brake pads produce dust as they wear. The ingredients in ceramic compounds produce a light-colored dust that is much less noticeable and less likely to stick to the wheels. Ceramic pads meet or exceed all original equipment standards for durability, stopping distance, and noise.

This is quite an improvement over organic and semimetallic brake materials that typically sacrifice pad life to reduce noise, or vice versa.

Frequently Asked Question

Use of Copper in Brake Pads

Copper is a soft metal with very high thermal and electrical conductivity and is used in most brake lining/pads because it:

- Helps transfer heat efficiently and increases brake effectiveness in cold weather
- Helps prevent brakes from squeaking and shuddering
- Adds strength to the brake pad material
- Helps reduce fade so that brakes remain effective through extended braking events.

Not all brake pads contain copper. Copper content varies from manufacturer to manufacturer and even among pads made by the same manufacturer for different applications.
used in automotive brake pads. Both bills mandate that brake pads sold in each state contain no more than 0.5% of copper by weight and must meet all applicable safety standards. The laws differ in timing. In California, the law takes effect in no later than January 1, 2025.

**LEAF MARK** Washington State legislation mandates that all brake pads and shoes manufactured after January 1, 2015, are required to have a leaf mark icon indicating the level of compliance with state friction material content legislation. To demonstrate brake manufacturers’ compliance with new state regulations, the Brake Manufacturers Council (BMC) of the Automotive Aftermarket Suppliers Association and the Motor and Equipment Manufacturers Association (MEMA) have selected NSF International to serve as its official registrar. NSF International is an independent organization that writes standards, tests, and certifies products for the food, water, and consumer goods industries to minimize adverse health effects and protect the environment (www.nsf.org). In addition to copper, all of the new standards restrict the following from brake friction materials:

- Asbestos fibers, less than 0.1% by weight
- Cadmium and its compounds, less than 0.01% by weight
- Chromium (VI)-salts, less than 0.1% by weight
- Lead and its compounds, less than 0.1% by weight
- Mercury and its compounds, less than 0.1% by weight

The leaf marks refer to the following ratings:

- **Level “A” standard (one leaf):** Contains more than 5% of copper by weight (2015 Standard)
- **Level “B” standard (two leaves):** Contains between 0.5% and 5% of copper by weight (2021 Standard)
- **Level “N” standard (three leaves):** Contains less than 0.5% of copper by weight (2025 Standard)

**FIGURE 4–11** All boxes of brake linings and pads should be labeled with the leaf mark, which gives a visual clue as to the standard under which the brake friction materials meet certain state laws regarding the amount of copper.

Starting in 1964, brake linings have been using a standardized way to identify the brake lining materials. The edge codes follow the Society of Automotive Engineers (SAE) Standard J866a.

**EDGE CODE INFORMATION** After January 1, 2014, all brake shoes and pads were required to have manufacturer’s edge codes which indicate all of the following:

- Company code
- Pad number
- Formulation code
- Vendor number
- Friction code
- Week number that the brakes were made
- Environmental code (A, B, or N)
- Year of manufacture

Because these edge codes now contain so much information, many manufacturers of brake friction material print this information on the backing of the friction material instead of on the edge of the lining to make it easier to see and read. **SEE FIGURE 4–12 AND 4–13.**

**COEFFICIENT OF FRICTION EDGE CODE** The edge codes for the coefficient of friction include letters that represent a range of coefficient of friction. **SEE CHART 4–5.**

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**FIGURE 4–12** The edge codes include a lot of information about the brake friction material.
There are always two letters used side by side and the first letter indicates the coefficient of friction when brakes are cold (250°F/121°C), and the second letter indicates the coefficient of friction of the brake lining when the brakes are hot (600°F/316°C). For example, FF indicates that the brake lining material has a coefficient of friction between 0.35 and 0.45 when both cold and hot.

In Figure 4–14, typical drum brake lining edge codes, showing the coefficient of friction codes for cold and hot circled.

### Chart 4–5

<table>
<thead>
<tr>
<th>Code Letter</th>
<th>Coefficient of Friction Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code C</td>
<td>0.00–0.15</td>
</tr>
<tr>
<td>Code D</td>
<td>0.15–0.25</td>
</tr>
<tr>
<td>Code E</td>
<td>0.25–0.35</td>
</tr>
<tr>
<td>Code F</td>
<td>0.35–0.45</td>
</tr>
<tr>
<td>Code G</td>
<td>0.45–0.55</td>
</tr>
<tr>
<td>Code H</td>
<td>0.55 and above</td>
</tr>
<tr>
<td>Code Z</td>
<td>Ungraded</td>
</tr>
</tbody>
</table>

**Edge Code Letters Do Not Represent Quality**

The coefficient of friction letters do not mean the relative quality of the lining material. Lining wear, fade resistance, tensile strength, heat recovery rate, wet friction, noise, and coefficient of friction must be considered when purchasing high-quality linings. For best brake performance, always purchase the best-quality brake pads and lining from a well-known brand name.

**Cold and Hot Coefficient of Friction**

There are always two letters used side by side and the first letter indicates the coefficient of friction when brakes are cold (250°F/121°C), and the second letter indicates the coefficient of friction of the brake lining when the brakes are hot (600°F/316°C). For example, FF indicates that the brake lining material has a coefficient of friction between 0.35 and 0.45 when both cold and hot. **See Figure 4–14.**
exposure can cause scar tissue to form in the lungs and can also cause cancer.

9. Semimetallic refers to brake lining material that uses metal rather than asbestos in its formulation.

10. Brake pads and linings that are called non-asbestos, non-asbestos organic (NAO), or non-asbestos synthetic (NAS) use synthetic material such as aramid fibers instead of steel. These friction materials are often called ceramic in the American aftermarket because they include ceramic fibers which are usually potassium titanate.

11. Studies indicated that brake pads were a major source of copper in the runoff. California and Washington in 2010 passed laws mandating a reduction in the amount of copper used in automotive brake pads. Washington State legislation mandates that all brake pads and shoes manufactured after January 1, 2015, are required to have a leaf mark icon indicating the level of compliance with state friction material content legislation.

12. After January 1, 2014, all brake shoes and pads were required to have manufacturer’s edge codes which indicate all of the following:
   - Company code
   - Pad number (part number)
   - Formulation code
   - Vendor number
   - Friction code
   - Week number that the brakes were made
   - Environmental code (A, B, or N)
   - Year of manufacture

**REVIEW QUESTIONS**

1. What is kinetic energy?
2. What is meant by the coefficient of friction?
3. Why do brakes fade due to excessive heat or water?
4. Why is asbestos being restricted in brake friction materials?
5. What is the difference between semimetallic and non-asbestos organic (NAO) brake friction materials?
6. Which type of brake pad material is often referred to as ceramic?
7. Why is copper being removed from brake friction material?
8. What is the meaning of the friction code letter printed on the edge of brake linings and pads?

**CHAPTER QUIZ**

1. Which Greek letter is used to represent the coefficient of friction?
   - a. Mu (μ)  
   - b. Omega (Ω)  
   - c. Delta (Δ)  
   - d. Pi (π)

2. The amount of asbestos in brake friction material is being restricted because____.
   - a. It does not transfer heat to the drum/rotor  
   - b. It is a health hazard  
   - c. Asbestos worn from brakes contaminate rivers and streams  
   - d. It causes excessive brake drum/rotor wear

3. What type of binder is used in all brake friction materials?
   - a. Rubber scrap  
   - b. Carbon  
   - c. Phenolic resin  
   - d. Ceramic powders

4. An edge code reading for coefficient of friction is EF. This means____.
   - a. The coefficient of friction is 0.50  
   - b. The coefficient of friction is higher when the brakes are cold  
   - c. The coefficient of friction is higher when the brakes are hot  
   - d. A higher quality brake would have a code of FF

5. Brake pads and linings that use synthetic material such as aramid fibers instead of steel are usually referred to as____.
   - a. NAO  
   - b. NAS  
   - c. Ceramic  
   - d. Any of the above

6. What type of brake pad material is often referred to as ceramic?
7. Why is copper being removed from brake friction material?
8. What is the meaning of the friction code letter printed on the edge of brake linings and pads?
9. The lowest level of copper in brake friction material is shown on the leaf mark as____.
   - a. A single leaf  
   - b. Two leaves  
   - c. Three leaves  
   - d. Four leaves

10. Disc brake pads can reach temperatures as high as____.
   - a. 300°F (150°C)  
   - b. 1,000°F (540°C)  
   - c. 1,300°F (700°C)  
   - d. 1,800°F (980°C)