

TABLE OF CONTENTS



Biography	5	Brake Force and Corner Weight	37
Acknowledgments	5	Perfect Balance	38
Dedication	6	Static Weight Distribution	39
Foreword	6	The Second Law of Motion	39
Introduction	7	Dynamic Weight Distribution	40
Chapter 1: Energy Conversion	9	The Benefits of Perfect Balance	41
The Conservation of Energy	9	Front Brake Bias	43
Where Energy Comes From	10	Rear Brake Bias	43
Friction	10	Measuring Brake Balance	44
Kinetic Energy	11	Changing Brake Balance	44
Potential Energy	13	Chapter 5: Pedals, Boosters	
Energy Transformation	14	and Master Cylinders	46
Energy and the Brake System	14	Brake Pedal Components	46
Calculating Brake System Temperature	15	OEM Brake Pedals	47
Importance of Brake Sizing	15	Racing Brake Pedals	48
Chapter 2: Tires Stop the Car	18	Brake Boosters	48
The First Law of Motion	18	Vacuum Boosters	48
Brake Forces	18	Hydraulic Boosters	50
Tire Slip	19	Master Cylinders	50
How Brake Forces are Generated	20	Master Cylinder Selection	52
The Mu-Slip Curve	22	Rear Brake Pressure Reduction	54
Choosing the Best Tires	24	Balance Bars	54
Calculating Maximum Deceleration	25	Proportioning Valves	55
Chapter 3: Brake System Design	27	Chapter 6: Brake Fluid	58
Driver Applied Force	27	Brake Fluid 101	58
Brake System Overview	28	FMVSS116	58
Brake Corner Gain	33	Dry Boiling Point	60
Summing Forces	34	Wet Boiling Point	61
Overall Brake System Gain	34	Water Adsorption	61
Calculating Deceleration	34	DOT Ratings	61
Calculating Stopping Distance	34	Brake Fluid Compatibility	64
Brake System Modifications	35	Brake Fluid Maintenance	64
Chapter 4: Brake Balance	37	Brake Bleeding	65
		Chapter 7: Brake Lines and Hoses	69

TABLE OF CONTENTS



Hydraulic Circuit Design	69		
Brake Lines	70		
Flare Fittings	70		
Brake Hoses	71		
Banjo Fittings	72		
Stainless Steel Brake Hoses	73		
Chapter 8: Brake Calipers	76	Chapter 11: Sports Car Brake Upgrade	118
Hydraulic Gain	76	The Vehicle	119
Caliper Components	76	The Objective	119
Taper Wear	79	Picking the Right Parts	119
Piston Count	81	Bolting Them On	121
Caliper Mounting	82	The Results	124
One-Piece (Monoblock) Calipers	84		
Two-Piece Calipers	84	Chapter 12: Racecar Brake Upgrade	126
Knockback	84	The Vehicle	127
		The Objective	127
Chapter 9: Brake Pads	88	Front Brake Upgrade	127
Brake Pad Terminology	88	Rear Brake Upgrade	129
Coefficient of Friction	90	Apply System Upgrade	131
Coefficient of Friction Stability	91	Hoses, Fluids, and Pads	132
Brake Pad Fade	91	The Results	132
Friction Material Categories	92		
Friction Material Chemistries	93	Chapter 13: Muscle Car Brake Upgrade	133
Friction Mechanisms	96	The Vehicle	133
Brake System Break-In	97	The Objective	134
		Drum Brakes 101	134
Chapter 10: Brake Rotors	100	Picking The Right Parts	134
A Rotor Refresher	100	Bolting Them On	135
Rotor Terminology	101	Buttoning it Up	138
Effective Radius	103	The Results	138
Rotor Sizing	103		
Static Weight and Rotational Inertia	103	Chapter 14: Hot Rod Brake Upgrade	139
Rotor Cooling	104	The Vehicle	139
One-Piece (Fixed) Rotors	107	The Objective	139
Two-Piece (Floating) Rotors	107	Front Brake Upgrade	139
Solid Rotors	109	Brake Pedal Considerations	140
Vented Rotors	110	Master Cylinder Upgrade	142
Cross-Drilled Rotors	111	Brake Line and Proportioning	
Slotted Rotors	112	Valve Installation	142
Rotor Inspection	113	Brake Hoses	143
Thickness Variation	115	Brake Fluid Selection	143
		Parking Brake Installation	144
		The Results	144



BRAKE PADS

Due to operating wear and tear, brake pads are one of the most commonly replaced components in the brake system. They also happen to have a significant impact on overall brake system gain as stated back in Chapter 3. Consequently, upgraded pads are one of the most common brake system modifications.

However, in this context the word upgrade must be used with great care. While your local auto supply store likely offers a combination of premium, high-performance, heavy-duty, and severe-use brake pads, there are no industry standards for what constitutes a premium, high-performance, heavy-duty, or severe-use brake pad.

The same lack of formal definition applies to semi-metallic, non-asbestos

organic, ceramic, and other exotic brake pad chemistries. In all of these cases, the manufacturer is free to call the pads by whatever name they see fit. Consequently, brake pad selection is a bit of a black art.

Okay, so there's a lot of black art involved, but that should not discourage you from trying to find the best brake pads for your vehicle. Good materials are out there, but be forewarned that finding the best pads for your application can sometimes involve some trial and error. Therefore, you need to do some homework to determine if the four pieces of friction material inside the cardboard box are suitable for your application, because the descriptions printed on the outside of the box are not very helpful at all.

Brake Pad Terminology

Before going any farther, it's time to define the nine critical features of a typical brake pad. That's right—in some applications, there are no less than nine brake pad design features that can impact its overall performance.

Friction Materials

The brake pad *friction material* is the primary wear element for the brake system. Sometimes called the *friction puck*, this sacrificial component is the only part of the brake pad that's designed to make contact with the rotor, converting kinetic energy into heat. As a result, over time it's slowly worn away until it needs replacing.

Of all the brake pad components discussed, the friction material is arguably the most critical from a high-performance perspective. There are countless varieties of



What differentiates one brake pad from another is the physical composition of its friction material. Like a fine suit, high-performance friction materials are custom-tailored to each application with a unique blend of ingredients. (Randall Shafer)

friction materials available in the marketplace, and the paragraphs that follow provide you with the information you need to navigate through the overwhelming number of choices.

Wear Sensors

Because all friction materials eventually wear out, a *wear sensor* is typically fitted to each pair of brake pads to inform the driver that replacement is required. Although electronic sensors are found on a few high-end European applications, in most cases a simple steel spring is riveted to the brake pad backing plate to serve this purpose.

When the friction material wears to the point that replacement is necessary, the spring will contact the rotor, emitting a high-pitched squeal. This audible signal should not be ignored, for if the friction material wears completely away, the rotor, caliper, or both may be susceptible to permanent damage.



Brake pad advertising is not bound by NHTSA regulations, and unfortunately there's only so much you can find out by looking at the parts in the box. They essentially all look the same to the untrained eye. Consequently, when picking out a brake pad for your application, it pays to do a little research first. (Randall Shafer)

BRAKE PADS



In some applications, a sensor is placed on the brake pad to alert the driver if the friction material is worn to its minimum thickness. While a spring on the backing plate can be used to emit an audible squeal under these conditions, the electronic sensor shown here informs the driver with a lamp on the instrument panel. (Randall Shafer/StopTech)

Backing Plates

Usually fabricated from simple low-carbon steel, the brake pad *backing plate* distributes forces from the caliper pistons to the friction material. Serrated features or through-holes in the backing plate can also serve to anchor and locate the friction material against the rotor and to transfer the brake pad friction force from the friction material to the caliper body.



The responsibility of the backing plates (red) is to transmit the force from the caliper pistons to the friction material. They may also contain retention features such as holes or serrated edges to provide a better anchor point for the friction material. (StopTech)

Thermal Barriers

Because of their steel construction, the backing plates generally do not insulate the caliper pistons from heat very effectively. Therefore, in many racing or high-performance applications a *thermal barrier* is found sandwiched between the friction material and the backing plate.

The two most common forms of insulator are the ceramic puck and the woven mat. In either case, the insulating material is bonded or riveted in place during the manufacturing process and cannot be added on later.



In order to reduce heat flow from the rotor to the brake fluid, a piece of insulating material can be placed between the backing plate and the caliper pistons. Stainless steel shims are the most common thermal barriers used in OEM applications and can also help to reduce certain noise frequencies. (Randall Shafer)

Adhesives

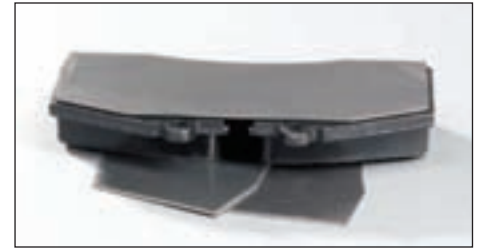
As the name implies, the brake pad *adhesive* bonds the friction material to the backing plate. While historically friction material has been held to backing plates with mechanical rivets, these high-temperature, high-strength glues are now the norm.

As you can image, selecting the proper adhesive is critical, considering a failure of the adhesive results in the friction material falling off of the backing plate. In this regard not all adhesives are created equal, and low-grade adhesives have been known to break down and de-bond in severe-duty applications.

Shims

Shims are usually thin stainless steel plates attached to the back side of the brake pad backing plate. They may also contain a thin layer of damping material (rubber in some cases) sandwiched between multiple stainless steel plates, but in any case these devices are used to damp out noises (squealing) that may be generated by the brake pad during use.

Note that the presence of shims does not necessarily guarantee noise-free performance, but in many applications they certainly help a great deal. A beneficial side



In racing applications, extreme measures are taken to keep heat out of the brake fluid. The shims shown above are fabricated from titanium, an excellent thermal insulator. Unfortunately, the cost of this material makes it impractical for production vehicles. (Randall Shafer/StopTech)

effect is that stainless steel shims can serve as an effective thermal barrier as well. For even better thermal insulation shims can be fabricated from titanium, but the cost of this material can be prohibitive.

Lubricants

Lubricants can serve two purposes. The first is to allow free motion between the brake pad and its mounts, or caliper abutment plates. This prevents binding and/or residual drag during use. This is generally a good thing.

In other applications, lubricant can be applied to the backing plate directly in an attempt to provide some measure of noise suppression. Frankly speaking, this is semi-effective at best. If this technique worked as well as some people claim, you would find it in widespread use among the vehicle manufacturers. It probably doesn't make matters worse, but don't expect a tube of goo to prevent long-term brake noise.



While advertised as a cure-all for brake noise, lubricants are really used to provide free motion between the backing plate and the caliper locating features. Too much lubricant can be detrimental though, as it collects dust, dirt, and debris over time. (Randall Shafer)