Better Brakes Enforcement Study, 2022

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Abstract

Washington State's Better Brakes Law, Chapter 70A.340 RCW, establishes restrictions on using certain toxic metals and asbestos in brake friction materials sold to people in Washington state. The law limits the use of asbestos, chromium (VI), lead, and mercury to less than or equal to 0.1% (1000 ppm), cadmium to less than or equal to 0.01% (100 ppm), and copper to less than or equal to 5% (50,000 ppm) in brake friction materials manufactured after January 1, 2021.

In 2022, the Washington State Department of Ecology conducted a study to assess the levels of cadmium, chromium(VI), lead, mercury, antimony, nickel, and zinc in brake friction materials. Ninety-nine brake products (brake pads and shoes) were purchased and tested for the study. The brake products collected represented a wide range of passenger, commercial, special use vehicles, original equipment, and aftermarket equipment.

When results were averaged, no brake friction material components tested in this study contained cadmium above the 100 ppm regulatory limit or chromium(VI), mercury, or lead above the 1,000 ppm limit. Five brake friction material components tested and labeled with manufacture dates after January 1, 2021, contained averaged results for copper above the current regulatory limit of 50,000 ppm. There are no regulatory limits for antimony, nickel, or zinc in brake friction materials.

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Background

In 2010, Washington State passed the Better Brakes Law (Chapter 70A.340 RCW), restricting the use of certain toxic metals and asbestos in brake friction materials. The law requires manufacturers of brake friction materials to report and certify their brake pads and shoes (referred to as “brake product” in this report) offered for sale in Washington State (Chapter 173-901 WAC). Specific exemptions and sell-off periods apply as detailed in Chapter 173-901-030 WAC.

Beginning in 2015, the law restricted the use of asbestos, hexavalent chromium (chromium(VI)), lead, and mercury to 0.1% (1,000 ppm) and cadmium to 0.01% (100 ppm). The law also established a two-tier provision to phase out copper content in brake friction materials to 0.5% (5,000 ppm) by 2025. The first tier began on January 1, 2021, and limits brake friction materials manufactured after January 1, 2021, to copper content less than or equal to 5% (50,000 ppm) by weight.

The Better Brakes Law requires that brake product packaging is labeled with one of the three levels of compliance based on the LeafMark™ system shown in Figure 1. Compliance levels A, B, and N indicate that the brake friction material contains specific levels of asbestos, chromium(VI), lead, mercury, cadmium, and copper. Brake products must also be marked with an edge code following the industry standard in SAE J2975. The edge code is a unique identification code located directly on the brake friction material. Part of the edge code includes the specific environmental compliance level letter (A, B, or N) and a two-digit abbreviation for the year of manufacture.

Level A: limits levels of asbestos, chromium(VI), lead, and mercury to less than or equal to 0.1 percent (1,000 ppm) and cadmium to 0.01 percent (100 ppm) by weight.
Level B: includes all the requirements of level A, and copper levels must be less than or equal to five percent (50,000 ppm) by weight.
Level N: includes all requirements of level A, and copper levels must be less than or equal to 0.5 percent (5,000 ppm) by weight.

Figure 1. Product package markings indicating compliance level of brake friction material based on the LeafMark™ system.

In 2017, Ecology conducted a product testing study of brake friction materials to assess concentrations of cadmium, copper, and lead (Wiseman 2018). Study results for 163 brake products indicated that no samples contained greater than 100 ppm cadmium, and four samples contained greater than the regulatory limit of 1,000 ppm for lead. Copper content was not limited at the time of the study, and averaged results ranged from 14 to 347,000 ppm (Wiseman 2018).

Ecology conducted this 2022 study to assess copper, cadmium, chromium(VI), lead, mercury, antimony, nickel, and zinc levels in brake friction materials from brake products for sale in Washington. Ninety-nine brake products were purchased and tested for this study. Study data were collected and validated for compliance evaluations and enforcement of the Better Brakes Law. These data may also be used to verify the accuracy of manufacturer self-reporting in the NSF International database of registered friction material.

Methods

Product Collection

Between August and September 2022, Ecology purchased and received 99 brake products for this study. Products were purchased from 25 online stores, four dealerships, and four automotive parts stores in the south Puget Sound area of Washington. Products collected from NAPA Auto Parts and Parts Authority were purchased through Washington State Contract 12621 for purchasing automotive parts.

A data quality objective for this study was to collect up to 100 brake products intended for a wide variety of vehicle types (Nelson and Salamone 2022). Ecology originally purchased 100 brake products, but the vendor canceled one product order after the deadline for purchasing. As a result, 99 brake products were collected. Most of the products, 83 out of 99, were aftermarket parts, and 16 were original equipment parts.

The primary project goal was to assess friction materials from brake products manufactured as of January 1, 2021 (Nelson and Salamone 2022). Of the 99 products collected, 73 were manufactured after January 1, 2021, and 17 were manufactured before 2021 (Table A1). Nine products did not report a manufacture date as part of the edge code. Seven were labeled with compliance level A, 16 with compliance level B, and 71 with compliance level N (Table A1). Five products did not report a compliance level as part of the edge code.

Brake Drilling

Chain of custody (COC) was maintained throughout product collection, drill processing, and subsequent submission to the two testing laboratories.

All 99 brake products were shipped via FedEx to Link Engineering Company, located in Dearborn, Michigan, for sample processing into components for analysis. Pneumatic drill processing was used to generate uniform granular particulates for metals testing following method SAE J2975. Brake friction material components were collected as drilled turnings into one plastic bag for each product. The bag's contents were then split into two vials for submission to the two testing laboratories used for this study. A total of nine drill processing blanks, one for each batch of drill processing, were collected to assess potential bias by environmental contamination. Three storage container blanks were also collected to assess potential container contamination.

Laboratory Analysis

Brake friction material components from all 99 brake products were shipped in two vials from Link Engineering Company to Ecology's Manchester Environmental Laboratory (MEL) in Port Orchard, Washington. MEL analyzed the samples for cadmium, copper, lead, antimony, nickel, and zinc using EPA method 6020B and mercury using EPA method 7471B. MEL shipped one vial of brake friction material components from all 99 brake products to Eurofins Lancaster Laboratories Environmental (ELLE) in Lancaster, Pennsylvania, for chromium(VI) analysis using EPA method 7199.

Data Quality

The study quality assurance project plan (QAPP) specified analysis of all analytes by EPA method 6010D (Nelson and Salamone 2022). Accreditation for analysis by EPA method 6010D would have delayed the completion of this study by an unacceptable length of time. Analysis of cadmium, copper, lead, antimony, nickel, and zinc was instead performed using accredited EPA method 6020B (Table 1). Mercury analysis was performed using accredited EPA method 7471B (Table 1).

Table 1. Laboratory procedures and project reporting limits used in the 2022 Better Brakes study.

Analyte	Number of Samples	Matrix	Original QAPP Method	Original QAPP[1] RL	Analysis Method	Adjusted Project RL
Cadmium, Copper, Lead, Antimony, Nickel, Zinc	99	Brake Friction Material	EPA 6010D	10 ppm	EPA 6020B	10 ppm (Except 50 ppm for zinc)
Mercury	99	Brake Friction Material	EPA 6010D	10 ppm	EPA 7471B	100 ppm
Chromium(VI)	99	Brake Friction Material	EPA 7199	0.3 ppm	EPA 7199	100 ppm
Cadmium, Copper, Lead, Antimony, total Chromium[2], Nickel, Zinc	11	Storage and Drill Processing Blanks (Water)	EPA 200.8	0.5 ppm	EPA 200.8	1 ppm (Except 5 ppm for zinc)
Mercury	1	Storage Blanks (Water)	EPA 7470A	0.5 ppm	EPA 7470A	0.5 ppm

QAPP = Quality Assurance Project Plan; RL = Reporting Limit.
[1] Nelson and Salamone (2022).
[2] Drill processing blanks (water) were tested for total chromium as a surrogate blank for chromium(VI).

A data quality objective specified in the study QAPP was to analyze all brake friction material components in duplicate for all metal analytes. All testing for cadmium, copper, lead, mercury, antimony, nickel, and zinc in brake friction material was performed in duplicate. Chromium(VI) testing was performed in duplicate for 20 samples but singularly for 79 samples since the laboratory had a limited volume of sample material.

A Stage 3 data validation was completed on reported cadmium, copper, lead, mercury, antimony, nickel, and zinc results following specifications in the QAPP (Nelson and Salamone 2022). A Stage 4 validation was completed on the chromium(VI) data. Validation evaluates and documents that data quality, including analytical precision, sensitivity, and bias, is acceptable. The principal investigator verified these data for completeness, correctness, and conformance to the study data quality objectives. The laboratory results are usable as qualified.

A method quality objective (MQO) for analytical precision was the relative standard deviation (RSD) of replicate analyses of all analytes, as recommended in SAE J2975. After all laboratory data was validated, RSD for samples with duplicate analysis of an analyte was calculated. RSD involving results below the project RL were calculated at the RL value. Samples and duplicates with an RSD equal to or greater than 20% are qualified as estimates (J). The RSD exceedances are listed in bold in Appendix Table A2.

Cadmium, Copper, Lead, Antimony, Nickel, and Zinc

Analysis of brake friction material components for cadmium, copper, lead, antimony, nickel, and zinc was specified to have a target reporting limit (RL) of 10 ppm for all analytes. The RL was met for analysis of cadmium, copper, lead, antimony, and nickel (Table 1). The RL for zinc was raised to 50 ppm due to sample dilutions required to mitigate matrix interferences and to protect the instrument from contamination during testing.

Two storage blanks and nine drill processing blanks were tested for cadmium, copper, lead, antimony, total chromium (as a surrogate blank for chromium(VI)), nickel, and zinc. No data qualification was required for any analyzed sample based on an assessment of storage and processing blank recoveries.

A measurement quality objective (MQO) for analytical precision was matrix spike recoveries between 75 – 125% and relative percent difference (RPD) of less than 20% between the matrix spike (MS) and matrix spike duplicate (MSD). The following brake friction material component duplicates were qualified as estimates (J) due to matrix spikes that did not meet the recovery MQO, RPD MQO, or both:

- AAP-3-2-1 for copper and zinc
- ANM-1-1-1 for zinc
- CAR-2-2-1 for copper and lead
- GWR-1-1-1 for zinc
- NPL-1-3-1 for zinc.

Mercury

The RL for mercury was adjusted to 100 ppm (Table 1) due to limited sample volume, required sample dilutions to mitigate matrix interferences, and to protect the instrument from contamination during testing. The adjusted RL met the needs of the study goals and objectives.

One storage blank sample was tested for mercury. Mercury was not detected in the storage blank above the RL; however, the result is qualified as an estimate (UJ) that may be biased low since the holding time of 28 days had expired. No drill processing blanks were analyzed for mercury since the laboratory had a limited volume of sample material.

All other MQOs for mercury were met, and the results are usable as qualified.

Chromium(VI)

The RL for chromium(VI) was adjusted to 100 ppm (Table 1) due to the limited sample volume of brake friction material and additional sample dilutions required to mitigate matrix interferences during testing. The adjusted RL met the needs of the study goals and objectives.

An MQO for the laboratory continuing calibration verification (CCV) standard recoveries was specified to be 90 – 110%. The following brake friction material component duplicate chromium(VI) results were qualified as rejected (REJ) due to CCV standard recovery equal to or less than 30%:

- AAP-3-2-1 (only one duplicate qualified REJ)
- AAPS-1-1-1
- AAPS-1-2-1
- AAZ-1-1-1
- AM-48-1-1
- ANM-1-1-1
- ANT-1-1-1
- AAP-1-1-1
- AZ-3-1-1.

The following brake friction material component duplicate chromium(VI) results were qualified as estimates (J) due to CCV standard recovery at 80%: AM-48-2-1, AM-49-1-1, AM-49-2-1. The following brake friction material component singular chromium(VI) results were qualified as not detected above the reporting limit, with the reporting limit being an estimated value (UJ) due to CCV standard recovery at 88%:

- PAA-1-2-1
- PAA-1-3-1
- PAA-1-4-1
- PAA-1-5-1
- PAA-1-6-1
- PAA-1-7-1
- PAA-1-8-1
- PAA-1-9-1
- PAA-1-20-1
- PAA-1-21-1.

Results

Ninety-nine brake friction material components were analyzed in duplicate for cadmium, copper, lead, antimony, mercury, nickel, and zinc, generating 1,386 individual test results. Additionally, 20 brake friction material components were analyzed in duplicate, and 79 were analyzed singularly for chromium(VI), generating 119 individual test results. The total number of individual test results generated, reviewed, and entered into the product testing database (PTDB) for this study was 1,505.

Cadmium, Copper, Lead, Antimony, Nickel, and Zinc

Table 3. Summary statistics of test results for brake friction material components analyzed for cadmium, copper, lead, antimony, nickel, and zinc in the 2022 Better Brakes study.

Analyte	Cadmium	Copper	Lead	Antimony	Nickel	Zinc
Number of Results[1] (N)	198	198	198	198	198	198
N > Project RL	2	194	142	117	192	161
Maximum (ppm)	19.9	366,000	892	49,100	287	76,800
Minimum (ppm)	18.9	13.6	11.7	10.7	10.1	50.7

[1]One friction material component sample was analyzed in duplicate per product.
RL = Reporting Limit; ppm = parts per million.

Cadmium results were above the project RL of 10 ppm in two brake friction material component samples. Cadmium results ranged from 18.9 to 19.9 ppm (Table 3).

One hundred ninety-four out of 198 brake friction material component results for copper were above the project RL of 10 ppm (Table 3). Individual results for copper ranged from 13.6 to 366,000 ppm.

One hundred forty-two out of 198 brake friction material component results for lead were above the project RL of 10 ppm and ranged from 11.7 to 892 ppm (Table 3).

Reported results above the project RL (N = 117) for antimony ranged from 10.7 ppm to 49,100 ppm. Reported results above the project RL (N = 192) for nickel ranged from 10.1 to 287 ppm. Reported results above the project RL (N = 161) for zinc ranged from 50.7 to 76,800 ppm.

Mercury and Chromium(VI)

No test results for mercury or chromium(VI) were greater than the project RL of 100 ppm.

Discussion

Study products and data were collected and validated following the study's QAPP (Nelson and Salamone 2022) for compliance evaluation and enforcement of the Better Brakes Law.

Duplicate analysis values for all product components were averaged, and relative standard deviation was calculated following the study QAPP (Nelson and Salamone 2022). Average values are reported in Appendix Table A2 and are not recorded in the PTDB. The following discussion items are in terms of the average analyte values.

No brake products had friction material components that contained averaged cadmium results above the 100 ppm limit or chromium(VI), mercury, or lead above the 1,000 ppm limit.

Fourteen brake products had friction material components that contained averaged copper results at greater than 50,000 ppm (Figure 1). Eleven product components contained averaged copper results at greater than 5,000 ppm but less than 50,000 ppm. The remaining 74 products contained averaged copper results at less than 5,000 ppm, which meets the specifications of compliance level N. Five products labeled with manufacture dates after January 1, 2021, had friction material components with average concentrations of copper more than 50,000 ppm (Figure 2). These five brake products do not meet the 2021 regulatory criteria for copper in brake products.

This study detected antimony in 59 brake product components, nickel in 99 brake product components, and zinc in 85 brake product components at average levels above the project RLs. There are no regulatory limits for antimony, nickel, or zinc in brake products.

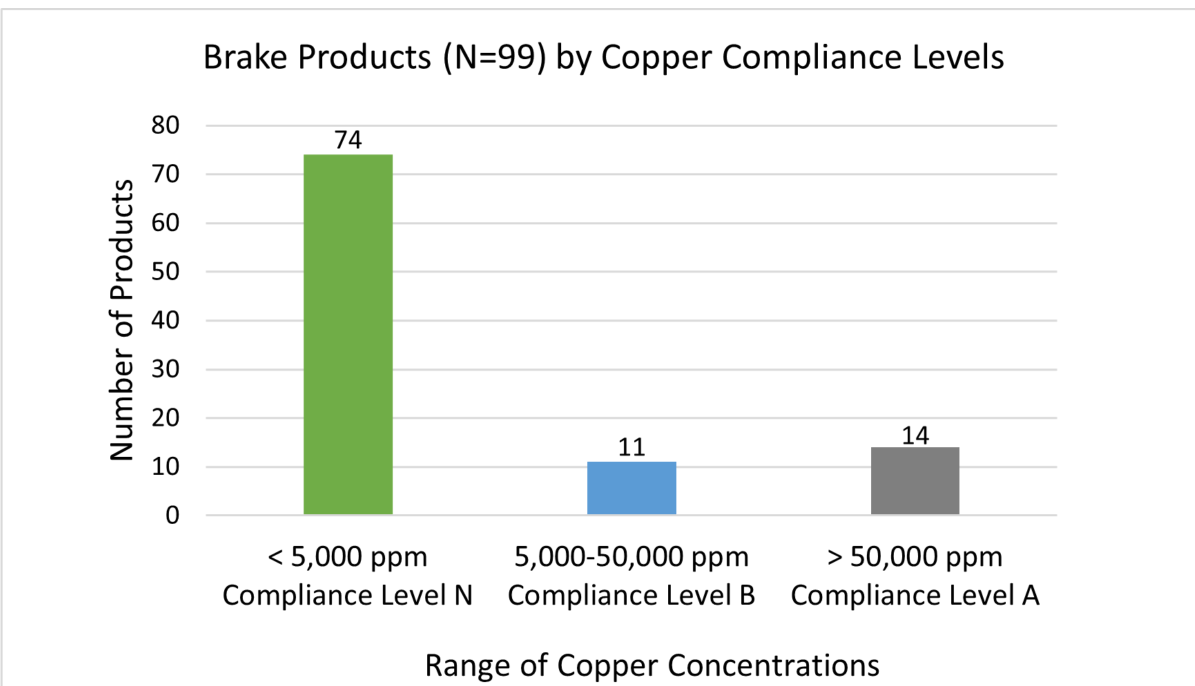

Figure 2. Summary of averaged copper results in brake friction material components by compliance levels for brake pad and shoe products tested in the 2022 Better Brakes Study

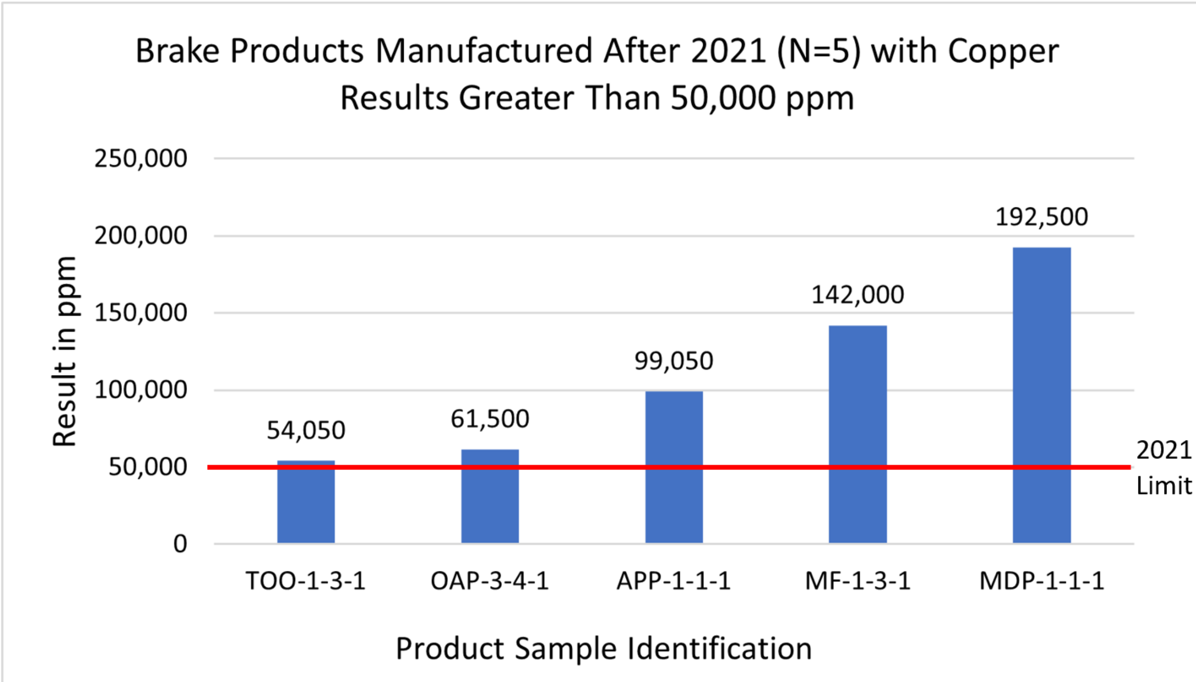

Figure 3. Summary of brake friction material components with a reported manufacture date of 2021 or later with averaged copper results greater than 50,000 ppm in the 2022 Better Brakes Study.

References

Nelson, K., and A. Salamone. 2022. Quality Assurance Project Plan: Better Brakes Enforcement Study 2022. Publication 22-03-110. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/UIPages/SummaryPages/2203110.html

Wiseman, C. 2018. Better Brakes Enforcement Study 2017. Publication 18-04-003. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/1804003.html

Appendix A. Summary of Components and Averaged Results

Table A1. Summary of brake friction material components of each brake pad and shoe analyzed in the 2022 Better Brakes study.

Friction Material Component ID	Vehicle Category[1]	Manufacture Year[2]	Compliance Code[3]
AAP-3-1-1	Medium car	2022	N
AAP-3-2-1	Truck	2022	B
AAPS-1-1-1	Medium car	2021	N
AAPS-1-2-1	Truck	2022	B
AAZ-1-1-1	Mini car	2019	N
AM-48-1-1	Compact car	2018	B
AM-48-2-1	Medium car	2022	N
AM-49-1-1	Heavy car	2022	B
AM-49-2-1	Heavy car	2022	B
ANM-1-1-1	Heavy car	2021	N
ANT-1-1-1	Truck	2020	N
APP-1-1-1	SUV	2021	A
AZ-3-1-1	Truck	2021	N
AZ-3-2-1	Medium car	2022	N
AZ-3-3-1	Bus	2021	N
BBK-1-1-1	Medium car	2015	B
BBK-2-1-1	Semi-truck	2022	N
CAR-2-1-1	Heavy car	2021	N
CAR-2-2-1	SUV	2021	B
CAR-2-3-1	SUV	2022	N
CAR-2-4-1	Truck	2022	N
EEP-1-1-1	Mini car	2020	B
FIP-2-1-1	Police car	2022	N
FPR-1-2-1	Semi-truck	2021	N
FPR-1-3-1	Semi-truck	2021	N
FPR-1-4-1	Semi-truck	2022	N
FPR-2-1-1	Semi-truck	2021	N
GWR-1-1-1	Light car	—	—
HK-2-1-1	Medium car	—	—
HPC-1-1-1	Compact car, OE	2019	A
HPC-1-2-1	Light car, OE	2021	N
HPC-1-3-1	Medium car, OE	2020	A
HPD-1-1-1	Heavy car	2020	N
MDP-1-1-1	Mini car, OE	2021	A
MF-1-1-1	SUV, OE	2022	N
MF-1-2-1	Truck, OE	2022	N
MF-1-3-1	Heavy car, OE	2021	A

Friction Material Component ID	Vehicle Category[1]	Manufacture Year[2]	Compliance Code[3]
MMS-1-1-1	Medium car	—	—
NPL-1-10-1	Compact car	2022	B
NPL-1-1-1	Semi-truck	—	—
NPL-1-11-1	Compact car	2020	B
NPL-1-12-1	Compact car	2021	N
NPL-1-13-1	Compact car	2020	B
NPL-1-14-1	Light car	2022	N
NPL-1-2-1	Ambulance	2021	N
NPL-1-3-1	Heavy car	2020	N
NPL-1-4-1	SUV	2022	N
NPL-1-5-1	SUV	2022	N
NPL-1-6-1	Truck	2021	N
NPL-1-7-1	Van	2021	N
NPL-1-8-1	Medium car	2021	N
OAP-3-1-1	Compact car	2022	N
OAP-3-2-1	Compact car	2019	N
OAP-3-3-1	Compact car	2021	N
OAP-3-4-1	Heavy car	2021	B
OAP-3-5-1	Truck	2021	N
PAA-1-10-1	Semi-truck	2022	N
PAA-1-1-1	Ambulance	2022	N
PAA-1-11-1	Sports car	2021	B
PAA-1-12-1	SUV	—	N
PAA-1-13-1	SUV	2021	N
PAA-1-14-1	SUV	2022	N
PAA-1-15-1	Truck	2021	N
PAA-1-16-1	Truck	2021	N
PAA-1-17-1	Compact car	2022	N
PAA-1-18-1	Truck	2021	N
PAA-1-19-1	Van	—	A
PAA-1-20-1	Van	—	B
PAA-1-2-1	Bus	2022	N
PAA-1-21-1	Van	2021	N
PAA-1-3-1	Compact car	2022	N
PAA-1-4-1	Compact car	2021	N
PAA-1-5-1	Heavy car	2020	N
PAA-1-6-1	Medium car	—	N
PAA-1-7-1	Medium car	2022	N
PAA-1-8-1	Police car	2021	N
PAA-1-9-1	Semi-truck	2021	N
PG-2-1-1	Medium car	2021	N

Friction Material Component ID	Vehicle Category[1]	Manufacture Year[2]	Compliance Code[3]
PG-2-2-1	Sports car, OE	2020	A
PG-2-3-1	SUV	2022	N
PG-2-4-1	Heavy car	2020	N
PTP-1-1-1	Semi-truck	2022	N
PTP-1-2-1	Semi-truck	2022	N
RTR-1-1-1	Truck	2021	N
RTR-1-2-1	SUV	2021	N
SMR-2-1-1	Heavy car	2020	N
SWA-2-1-1	SUV	2022	N
TCN-2-1-1	Heavy car, OE	2022	N
TCN-2-2-1	Light car, OE	2022	N
TMS-1-1-1	Heavy car	2020	N
TOO-1-1-1	Compact car, OE	2022	N
TOO-1-2-1	Light car, OE	2022	B
TOO-1-3-1	SUV, OE	2022	B
TOO-1-4-1	Medium car, OE	2022	N
TW-2-1-1	SUV, OE	2021	N
TW-2-2-1	Truck, OE	2022	N
WEF-1-1-1	Bus	2021	N
WEF-2-1-1	Refuse truck	—	—
WEF-2-2-1	Refuse truck	2022	N

[1]All are aftermarket parts except those described as OE.
[2]Manufacture year as reported on the edge code. Field is blank if information was not reported.
[3]Compliance code as reported on the edge code. Field is blank if information was not reported.
SUV = Sport Utility Vehicle.
OE = Original Equipment.

Table A2. Summary of analytical result averages and relative standard deviation (RSD) for brake friction material analyzed in the 2022 Better Brakes study.

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
AAP-3-1-1	Antimony	16	0.4
AAP-3-1-1	Copper	4315	10.3
AAP-3-1-1	Lead	49	2.9
AAP-3-1-1	Nickel	58	4.1
AAP-3-1-1	Zinc	58150	12.8
AAP-3-2-1	Antimony	39500	4.3
AAP-3-2-1	Copper	1935	11.3
AAP-3-2-1	Lead	79	3.7
AAP-3-2-1	Nickel	14	10.2
AAP-3-2-1	Zinc	2310	1.2
AAPS-1-1-1	Copper	38650	12.3
AAPS-1-1-1	Lead	33	4.2
AAPS-1-1-1	Nickel	49	0.0
AAPS-1-1-1	Zinc	600	2.1
AAPS-1-2-1	Antimony	18550	2.7
AAPS-1-2-1	Copper	8190	**23.7**
AAPS-1-2-1	Lead	106	2.0
AAPS-1-2-1	Nickel	15	1.9
AAPS-1-2-1	Zinc	17950	1.2
AAZ-1-1-1	Copper	5555	1.1
AAZ-1-1-1	Lead	17	2.9
AAZ-1-1-1	Nickel	105	3.4
AAZ-1-1-1	Zinc	215	1.0
AM-48-1-1	Copper	82350	16.1
AM-48-1-1	Lead	19	7.0
AM-48-1-1	Nickel	101	1.7
AM-48-1-1	Zinc	9885	3.1
AM-48-2-1	Antimony	37000	1.9
AM-48-2-1	Copper	17	1.2
AM-48-2-1	Lead	123	0.6
AM-48-2-1	Nickel	91	0.2
AM-48-2-1	Zinc	658	0.3
AM-49-1-1	Antimony	15	3.3
AM-49-1-1	Copper	20	8.5
AM-49-1-1	Nickel	32	1.1
AM-49-1-1	Zinc	60	2.4
AM-49-2-1	Copper	17	11.8
AM-49-2-1	Nickel	33	2.2
AM-49-2-1	Zinc	57	5.3

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
ANM-1-1-1	Antimony	13850	15.8
ANM-1-1-1	Copper	40	3.3
ANM-1-1-1	Lead	90	4.1
ANM-1-1-1	Zinc	958	2.1
ANT-1-1-1	Copper	410	1.6
ANT-1-1-1	Nickel	177	0.4
ANT-1-1-1	Zinc	286	4.2
APP-1-1-1	Copper	99050	5.6
APP-1-1-1	Lead	17	2.5
APP-1-1-1	Nickel	66	2.8
APP-1-1-1	Zinc	1155	4.3
AZ-3-1-1	Copper	3960	0.7
AZ-3-1-1	Lead	25	0.8
AZ-3-1-1	Nickel	65	0.4
AZ-3-1-1	Zinc	59400	1.2
AZ-3-2-1	Antimony	16	2.6
AZ-3-2-1	Copper	3835	0.9
AZ-3-2-1	Lead	31	0.2
AZ-3-2-1	Nickel	66	5.3
AZ-3-2-1	Zinc	55650	4.2
AZ-3-3-1	Antimony	19	2.6
AZ-3-3-1	Copper	146	3.9
AZ-3-3-1	Nickel	103	1.4
BBK-1-1-1	Antimony	12050	11.1
BBK-1-1-1	Copper	57950	**22.8**
BBK-1-1-1	Lead	65	5.1
BBK-1-1-1	Nickel	48	1.2
BBK-1-1-1	Zinc	38450	**21.5**
BBK-2-1-1	Antimony	10750	4.6
BBK-2-1-1	Copper	426	3.5
BBK-2-1-1	Lead	24	4.1
BBK-2-1-1	Nickel	192	4.1
CAR-2-1-1	Antimony	5760	4.2
CAR-2-1-1	Copper	82	3.3
CAR-2-1-1	Lead	33	3.2
CAR-2-1-1	Nickel	44	4.4
CAR-2-1-1	Zinc	9360	3.5
CAR-2-2-1	Antimony	45650	10.7
CAR-2-2-1	Copper	38900	12.0
CAR-2-2-1	Nickel	11	5.4
CAR-2-2-1	Zinc	162	5.2

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
CAR-2-3-1	Copper	167	3.4
CAR-2-3-1	Zinc	927	12.7
CAR-2-4-1	Antimony	28650	5.2
CAR-2-4-1	Copper	27	4.9
CAR-2-4-1	Lead	129	2.2
CAR-2-4-1	Nickel	36	2.0
CAR-2-4-1	Zinc	1275	0.6
EEP-1-1-1	Antimony	26950	16.5
EEP-1-1-1	Copper	69	7.5
EEP-1-1-1	Lead	138	3.6
EEP-1-1-1	Nickel	21	5.1
EEP-1-1-1	Zinc	55	8.1
FIP-2-1-1	Antimony	9425	4.3
FIP-2-1-1	Copper	28	3.3
FIP-2-1-1	Lead	22	10.5
FIP-2-1-1	Nickel	70	2.2
FIP-2-1-1	Zinc	243	3.2
FPR-1-2-1	Copper	30	4.7
FPR-1-2-1	Nickel	11	6.3
FPR-1-2-1	Zinc	2065	5.1
FPR-1-3-1	Copper	197	2.9
FPR-1-3-1	Lead	33	0.9
FPR-1-3-1	Zinc	2335	13.6
FPR-1-4-1	Copper	445	8.1
FPR-1-4-1	Lead	38	4.1
FPR-1-4-1	Nickel	16	7.6
FPR-1-4-1	Zinc	1760	8.0
FPR-2-1-1	Antimony	11	17.7
FPR-2-1-1	Copper	219	8.4
FPR-2-1-1	Lead	37	9.3
FPR-2-1-1	Zinc	2470	4.6
GWR-1-1-1	Antimony	25700	14.3
GWR-1-1-1	Copper	54	1.8
GWR-1-1-1	Lead	41	1.2
GWR-1-1-1	Nickel	32	**33.6**
GWR-1-1-1	Zinc	1385	5.6
HK-2-1-1	Antimony	165	3.0
HK-2-1-1	Copper	660	2.9
HK-2-1-1	Lead	354	4.0
HK-2-1-1	Nickel	33	0.6
HK-2-1-1	Zinc	3205	5.1

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
HPC-1-1-1	Copper	161000	9.7
HPC-1-1-1	Lead	18	12.3
HPC-1-1-1	Nickel	13	7.4
HPC-1-1-1	Zinc	8450	10.7
HPC-1-2-1	Copper	86	2.9
HPC-1-2-1	Zinc	12350	16.6
HPC-1-3-1	Antimony	4860	**30.8**
HPC-1-3-1	Copper	185500	4.2
HPC-1-3-1	Lead	32	0.2
HPC-1-3-1	Nickel	155	2.3
HPD-1-1-1	Copper	527	1.7
HPD-1-1-1	Nickel	274	2.6
HPD-1-1-1	Zinc	297	1.7
MDP-1-1-1	Antimony	4935	**58.3**
MDP-1-1-1	Copper	192500	1.1
MDP-1-1-1	Lead	15	1.9
MDP-1-1-1	Nickel	28	3.8
MDP-1-1-1	Zinc	1130	10.0
MF-1-1-1	Antimony	9345	6.4
MF-1-1-1	Copper	26	14.4
MF-1-1-1	Lead	23	4.0
MF-1-1-1	Nickel	66	0.3
MF-1-1-1	Zinc	235	1.5
MF-1-2-1	Copper	84	5.1
MF-1-2-1	Lead	18	2.8
MF-1-2-1	Nickel	149	3.8
MF-1-2-1	Zinc	312	5.2
MF-1-3-1	Copper	142000	5.0
MF-1-3-1	Lead	14	3.6
MF-1-3-1	Nickel	59	3.5
MF-1-3-1	Zinc	12900	0.0
MMS-1-1-1	Antimony	38500	1.1
MMS-1-1-1	Copper	62500	5.2
MMS-1-1-1	Lead	782	20.0
MMS-1-1-1	Nickel	147	5.8
MMS-1-1-1	Zinc	19900	**34.8**
NPL-1-10-1	Copper	31550	17.7
NPL-1-10-1	Lead	18	2.7
NPL-1-10-1	Nickel	133	3.7
NPL-1-10-1	Zinc	429	**22.9**
NPL-1-1-1	Antimony	11	12.5

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
NPL-1-1-1	Copper	127000	7.8
NPL-1-1-1	Lead	49	3.7
NPL-1-1-1	Nickel	222	5.1
NPL-1-1-1	Zinc	301	5.4
NPL-1-11-1	Antimony	78	7.6
NPL-1-11-1	Copper	39500	15.4
NPL-1-11-1	Lead	734	15.5
NPL-1-11-1	Nickel	269	10.3
NPL-1-11-1	Zinc	14800	18.2
NPL-1-12-1	Copper	527	0.1
NPL-1-12-1	Nickel	287	2.5
NPL-1-12-1	Zinc	754	10.9
NPL-1-13-1	Antimony	7040	15.9
NPL-1-13-1	Copper	55400	5.1
NPL-1-13-1	Lead	29	2.4
NPL-1-13-1	Nickel	40	1.2
NPL-1-13-1	Zinc	473	18.2
NPL-1-14-1	Antimony	27750	1.3
NPL-1-14-1	Copper	95	1.6
NPL-1-14-1	Lead	66	1.3
NPL-1-14-1	Nickel	19	**29.6**
NPL-1-14-1	Zinc	1295	2.7
NPL-1-2-1	Antimony	11	2.6
NPL-1-2-1	Copper	149	0.9
NPL-1-2-1	Nickel	65	2.6
NPL-1-3-1	Copper	126	0.0
NPL-1-3-1	Lead	18	0.4
NPL-1-3-1	Nickel	25	5.7
NPL-1-3-1	Zinc	11450	4.3
NPL-1-4-1	Copper	28	2.8
NPL-1-4-1	Nickel	131	0.5
NPL-1-5-1	Antimony	162	3.9
NPL-1-5-1	Copper	75	**34.5**
NPL-1-5-1	Nickel	86	4.0
NPL-1-5-1	Zinc	544	19.5
NPL-1-6-1	Antimony	5080	**41.2**
NPL-1-6-1	Cadmium	19	3.6
NPL-1-6-1	Copper	60	8.1
NPL-1-6-1	Lead	74	4.5
NPL-1-6-1	Nickel	17	3.3
NPL-1-6-1	Zinc	7860	15.8

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
NPL-1-7-1	Antimony	5455	11.0
NPL-1-7-1	Copper	17	2.0
NPL-1-7-1	Lead	24	0.3
NPL-1-7-1	Nickel	23	13.0
NPL-1-7-1	Zinc	9330	4.5
NPL-1-8-1	Antimony	34100	2.1
NPL-1-8-1	Copper	257	**78.6**
NPL-1-8-1	Lead	127	3.9
NPL-1-8-1	Nickel	41	7.6
OAP-3-1-1	Antimony	1945	4.0
OAP-3-1-1	Copper	5125	17.8
OAP-3-1-1	Lead	52	0.1
OAP-3-1-1	Nickel	67	0.0
OAP-3-1-1	Zinc	59000	8.4
OAP-3-2-1	Antimony	21	10.1
OAP-3-2-1	Copper	225	1.6
OAP-3-2-1	Nickel	90	0.5
OAP-3-3-1	Antimony	238	2.4
OAP-3-3-1	Copper	3825	1.3
OAP-3-3-1	Lead	24	0.6
OAP-3-3-1	Nickel	72	2.1
OAP-3-3-1	Zinc	56600	0.7
OAP-3-4-1	Antimony	8305	8.9
OAP-3-4-1	Copper	61500	15.2
OAP-3-4-1	Lead	71	**22.7**
OAP-3-4-1	Nickel	132	1.1
OAP-3-4-1	Zinc	21750	6.2
OAP-3-5-1	Antimony	21	8.6
OAP-3-5-1	Copper	3360	4.6
OAP-3-5-1	Lead	25	2.5
OAP-3-5-1	Nickel	22	1.0
OAP-3-5-1	Zinc	54800	9.0
PAA-1-10-1	Antimony	10450	2.0
PAA-1-10-1	Copper	469	3.0
PAA-1-10-1	Lead	21	0.7
PAA-1-10-1	Nickel	259	2.5
PAA-1-10-1	Zinc	87	4.5
PAA-1-1-1	Copper	195	0.4
PAA-1-1-1	Nickel	111	1.3
PAA-1-11-1	Copper	35500	2.8
PAA-1-11-1	Lead	19	3.8

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
PAA-1-11-1	Nickel	121	2.9
PAA-1-11-1	Zinc	433	5.6
PAA-1-12-1	Antimony	27050	7.6
PAA-1-12-1	Copper	29	1.2
PAA-1-12-1	Lead	120	1.8
PAA-1-12-1	Nickel	24	3.8
PAA-1-12-1	Zinc	1160	1.2
PAA-1-13-1	Antimony	5095	0.4
PAA-1-13-1	Copper	208	2.7
PAA-1-13-1	Lead	35	2.8
PAA-1-13-1	Nickel	84	1.5
PAA-1-13-1	Zinc	8610	4.3
PAA-1-14-1	Copper	308	3.0
PAA-1-14-1	Lead	18	0.8
PAA-1-14-1	Nickel	21	6.0
PAA-1-14-1	Zinc	4430	2.2
PAA-1-15-1	Copper	40	2.8
PAA-1-15-1	Nickel	35	0.2
PAA-1-15-1	Zinc	7240	0.8
PAA-1-16-1	Antimony	6975	0.1
PAA-1-16-1	Copper	339	4.2
PAA-1-16-1	Lead	14	1.5
PAA-1-16-1	Nickel	157	4.5
PAA-1-17-1	Nickel	14	4.7
PAA-1-17-1	Zinc	1160	15.8
PAA-1-18-1	Copper	156	0.9
PAA-1-18-1	Lead	12	3.0
PAA-1-18-1	Nickel	71	1.3
PAA-1-19-1	Antimony	26900	7.9
PAA-1-19-1	Copper	135500	0.5
PAA-1-19-1	Lead	39	3.7
PAA-1-19-1	Nickel	21	8.1
PAA-1-19-1	Zinc	579	11.6
PAA-1-20-1	Antimony	17800	11.9
PAA-1-20-1	Copper	19150	6.3
PAA-1-20-1	Lead	91	4.6
PAA-1-20-1	Nickel	97	5.4
PAA-1-20-1	Zinc	824	8.8
PAA-1-2-1	Antimony	11950	5.3
PAA-1-2-1	Copper	413	2.7
PAA-1-2-1	Lead	33	3.7

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
PAA-1-2-1	Nickel	191	1.1
PAA-1-2-1	Zinc	84	2.5
PAA-1-21-1	Antimony	10700	6.6
PAA-1-21-1	Copper	61	0.9
PAA-1-21-1	Lead	48	5.7
PAA-1-21-1	Nickel	92	6.8
PAA-1-21-1	Zinc	1410	4.0
PAA-1-3-1	Nickel	13	10.7
PAA-1-3-1	Zinc	1165	14.0
PAA-1-4-1	Copper	71	0.1
PAA-1-4-1	Nickel	41	0.9
PAA-1-4-1	Zinc	16350	11.7
PAA-1-5-1	Antimony	7795	11.3
PAA-1-5-1	Copper	85	1.2
PAA-1-5-1	Lead	35	1.2
PAA-1-5-1	Zinc	808	1.7
PAA-1-6-1	Antimony	26100	8.7
PAA-1-6-1	Copper	25	2.2
PAA-1-6-1	Lead	113	0.0
PAA-1-6-1	Nickel	24	0.6
PAA-1-6-1	Zinc	938	5.0
PAA-1-7-1	Antimony	101	**26.3**
PAA-1-7-1	Copper	2910	2.9
PAA-1-7-1	Lead	53	0.5
PAA-1-7-1	Nickel	79	2.0
PAA-1-7-1	Zinc	57800	2.2
PAA-1-8-1	Copper	6975	6.2
PAA-1-8-1	Nickel	182	0.8
PAA-1-8-1	Zinc	1805	2.0
PAA-1-9-1	Copper	167	1.7
PAA-1-9-1	Nickel	219	1.0
PG-2-1-1	Copper	74	2.3
PG-2-1-1	Nickel	42	1.8
PG-2-1-1	Zinc	14600	3.9
PG-2-2-1	Antimony	37500	2.3
PG-2-2-1	Copper	362000	1.6
PG-2-2-1	Lead	183	3.1
PG-2-2-1	Nickel	51	3.1
PG-2-2-1	Zinc	76400	0.7
PG-2-3-1	Copper	22	10.4
PG-2-3-1	Lead	23	2.5

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
PG-2-3-1	Nickel	17	3.3
PG-2-3-1	Zinc	455	11.7
PG-2-4-1	Antimony	25	6.9
PG-2-4-1	Copper	4255	1.2
PG-2-4-1	Lead	25	0.3
PG-2-4-1	Nickel	85	1.2
PG-2-4-1	Zinc	51650	6.4
PTP-1-1-1	Copper	74	11.9
PTP-1-1-1	Lead	14	12.8
PTP-1-1-1	Nickel	58	7.2
PTP-1-1-1	Zinc	2335	**23.9**
PTP-1-2-1	Antimony	289	7.3
PTP-1-2-1	Copper	46	5.4
PTP-1-2-1	Lead	18	3.1
PTP-1-2-1	Nickel	30	4.3
PTP-1-2-1	Zinc	2080	5.4
RTR-1-1-1	Copper	276	2.0
RTR-1-1-1	Nickel	143	2.0
RTR-1-2-1	Antimony	7545	5.2
RTR-1-2-1	Copper	19	5.2
RTR-1-2-1	Lead	30	0.0
RTR-1-2-1	Zinc	936	1.7
SMR-2-1-1	Antimony	15	0.9
SMR-2-1-1	Copper	373	3.4
SMR-2-1-1	Nickel	122	4.1
SMR-2-1-1	Zinc	976	10.8
SWA-2-1-1	Copper	29	3.7
SWA-2-1-1	Nickel	32	4.2
SWA-2-1-1	Zinc	7080	2.4
TCN-2-1-1	Antimony	1245	**134.7**
TCN-2-1-1	Copper	15	16.1
TCN-2-1-1	Lead	15	3.7
TCN-2-1-1	Nickel	13	4.4
TCN-2-1-1	Zinc	201	12.7
TCN-2-2-1	Antimony	6630	10.2
TCN-2-2-1	Copper	36	4.5
TCN-2-2-1	Lead	78	1.8
TCN-2-2-1	Nickel	72	2.5
TCN-2-2-1	Zinc	1195	5.3
TMS-1-1-1	Antimony	28	13.5
TMS-1-1-1	Copper	273	2.1

Friction Material Component ID	Analyte Name	Average Analysis Value (ppm)	Relative Standard Deviation (%)
TMS-1-1-1	Nickel	148	1.9
TMS-1-1-1	Zinc	52	1.6
TOO-1-1-1	Antimony	14850	4.3
TOO-1-1-1	Copper	32	0.7
TOO-1-1-1	Lead	43	1.7
TOO-1-1-1	Nickel	153	4.6
TOO-1-1-1	Zinc	6100	2.8
TOO-1-2-1	Copper	22400	**23.4**
TOO-1-2-1	Lead	17	5.8
TOO-1-2-1	Nickel	28	2.3
TOO-1-2-1	Zinc	679	5.0
TOO-1-3-1	Antimony	40	10.8
TOO-1-3-1	Copper	54050	9.8
TOO-1-3-1	Lead	15	5.0
TOO-1-3-1	Nickel	129	3.9
TOO-1-3-1	Zinc	14100	17.1
TOO-1-4-1	Copper	70	2.1
TOO-1-4-1	Lead	13	4.4
TOO-1-4-1	Nickel	32	6.3
TOO-1-4-1	Zinc	1390	**22.4**
TW-2-1-1	Copper	16	8.5
TW-2-1-1	Lead	14	3.0
TW-2-1-1	Nickel	16	4.0
TW-2-1-1	Zinc	59	1.6
TW-2-2-1	Copper	17	2.4
TW-2-2-1	Nickel	146	1.5
TW-2-2-1	Zinc	21150	1.7
WEF-1-1-1	Copper	181	1.6
WEF-1-1-1	Nickel	216	2.0
WEF-2-1-1	Antimony	10600	1.3
WEF-2-1-1	Copper	405	1.0
WEF-2-1-1	Lead	36	1.0
WEF-2-1-1	Nickel	183	1.2
WEF-2-1-1	Zinc	75	1.1
WEF-2-2-1	Antimony	6900	0.0
WEF-2-2-1	Copper	405	0.7
WEF-2-2-1	Lead	22	1.9
WEF-2-2-1	Nickel	271	0.5

Note. Average values and RSD are presented only for brake friction material component results that were above the project reporting limit and tested in duplicate. Exceedances for relative standard deviation greater than 20% are indicated in bold.