GASOLINE CONSUMPTION, TIRE WEAR AND COEFFICIENTS OF FRICTION ON VARIOUS ROAD SURFACES

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SYNOPSIS

The most important items in the cost of modern highway transportation which are affected by the surface are fuel, tire, and road costs Motor vehicle depreciation and maintenance costs are in general not appreciably affected by the type of road surface, such cost items having been made fairly stable by improvements in the car Gasoline and oil consumption tests indicated the importance of speed as a factor in vehicle operating costs, variations in cost due to changes in speed far outweighing surface effects At 52 miles per hour gasoline mileage was reduced 22 per cent from that obtained at 33 miles per hour, and oil consumption was about five times greater at the higher speed Tire wear not only varied with type of surface but on high grade types at 52 miles per hour tire wear increased as much as 2 7 times over that at 33 miles per hour Because of recent improvements in vehicle mechanics and equipment, the problem of determining variations in cost on various road systems has been greatly simplified and made susceptible to accurate computations

During 1936 the Iowa Engineering Experiment Station inaugurated a series of tests in which an attempt was made to correlate gasoline consumption, tire wear and coefficients of friction for five representative types of road surfaces The results of these tests reflect some of the improvements in vehicles, road surfaces and technique that are continually being made, and provide information which should be helpful in determining the costs of transportation on various types of road surfaces

The items of cost in the operation of a car which may be affected by the type and condition of the road surface and the distance travelled are gasoline, oil, tires and tubes, maintenance and repairs, and depreciation Previous tests conducted by the Iowa Engineering Experiment Station have provided a mass of information in regard to the gasoline consumption characteristics of various types of motor vehicles on different types of road surfaces Extensive tire wear data were reported at the Fourth Annual Meeting of the Highway Research Board by McNown[1] and at the Sixth Annual Meeting by Waller[2] and also by McNown

At the annual meeting in 1931, Anderson and Wright reported results of tire wear tests on two types of surfaces, portland cement concrete and "non-skid" asphaltic concrete [3]

Anderson and Wright measured tread wear by weighing and also by depth measurements As in previous tests lack of consistency was indicated in results by the weight method, but these tests indicated that consistent results could be obtained by the method of measuring tread depth Tests conducted by Moyer and reported at the Thirteenth Annual Meeting of the Highway Research Board[4] indicated that wide variations exist in

[1] "Investigation of Tire Wear" by W C McNown Proc Highway Research Board, Vol 4 (1924)

[2] "Tire Wear Investigation" by O L Waller Proc Highway Research Board, Vol 6 (1926)

[3] "Field Methods for Measuring Tire Wear" by A A Anderson and H B Wright Proc Highway Research Board, Vol 11 (1931)

[4] "Skidding Characteristics of Road Surfaces" by R A Moyer Proc Highway Research Board, Vol 13 (1933)

the skidding characteristics of road surfaces and also gave evidence of a definite relation between tire wear and the skidding characteristics of surfaces as measured by the coefficients of friction in the wet and dry condition

In the tests covered by this report, an effort was made to obtain as much information in regard to the effect of the type and condition of the road surface on the operating characteristics of the vehicle as was reasonably possible Gasoline consumption and tire wear were measured accurately on all of the surfaces tested There is no apparent reason why the oil consumption of a car equipped with air filters, and gas and oil filters should vary for different types of surfaces For this reason the only record of oil consumption kept in these tests was the amount of oil added to keep the oil level in the crankcase at the "full" mark This record was adequate to bring out clearly the increase in oil consumption caused by operating at higher speeds While some consideration was given to the two remaining items of cost affected by the distance travelled, maintenance and depreciation items, no accurate means was developed which could be used to determine the variations in these items which might be attributed to the surface In fact, the writer is inclined to believe that for the modern motor vehicle, built as ruggedly as it is, with all moving parts enclosed, with air, gas, and oil filters, the effect of dirt, dust, and ordinary surface roughness on maintenance and depreciation cost is negligible It is evident that speed has an important bearing on the operating cost of a car The average speed on dirt and gravel roads is notably lower than on smooth hard surfaces and operation at these reduced speeds may offset the slightly higher maintenance and depreciation costs which may be attributed to the surface Certain items of extra car maintenance due to dirt and untreated gravel roads should be considered these are extra car washing, the use of tire chains in mud, extra punctures, broken windshields due to gravel thrown by tires, and fender maintenance caused by wear due to loose gravel These items can be measured only at great expense by means of test cars However, it is believed that a fairly good estimate of the average cost of these items can be obtained from the daily records of the cost of operation of vehicles used by rural mail carriers Such a study is now being made by the Iowa Engineering Experiment Station If the general statement is accepted, that the type of surface has no variable effect on the maintenance and depreciation charges of the car, other than in these items, it seems reasonable that a fairly accurate estimate of the variable effect of different road surfaces on the cost of operation of vehicles can be obtained by combining the results of road tests with the results of studies of the cost records of cars operated by rural mail carriers While improvements in road surfaces are known to have contributed greatly to the reduction of transportation costs, everyone familiar with the facts will realize that the operation costs of motor cars today are affected far less by the condition of the road than the operating costs of cars of 1920 to 1930 vintage It seems fair to say that the problem of the effect of the surface on the cost of transportation has been greatly simplified by improvements in the car and that we may now expect to determine far more accurately than ever before the average cost of operation on various types of road surfaces

Further objectives in this investigation were determination of the variations in tire wear caused by modern road surfaces and correlation of tire wear with the skidding characteristics of the various types and conditions of road surfaces

Tire wear constitutes an important cost item Winfrey reported tire costs for the average car to be 0 43 cent per mile[5] and for the average truck in Iowa 1 01 cents per mile,[6] with values ranging from 0 25 cent per mile to one cent per mile for cars and from 0 69 cent per mile to 2 33 cents per mile for trucks

In the tests reported by Waller, McNown, and Anderson and Wright, there were indications that the kind of surface or its condition may cause differences to such an extent that wear on one surface may be five or six times that on another These extreme conditions were found largely on untreated gravel and macadam surfaces on which there was a considerable amount of loose, sharp, and hard aggregate, a type of construction more commonly used at the time of their tests, than today Nevertheless roads are being built today on which this surface condition still exists and the extreme tire wear and other characteristics which affect the cost of operation on them should be included in any analysis of modern highway transportation costs

Modern high speed travel has emphasized the need for road surfaces relatively free from the hazards of skidding, particularly when the surface is wet To provide this protection a rough surface texture is now generally formed on portland cement concrete by a belting or brooming operation On bituminous surfaces sand, pea gravel, or rock chips of varying size are used as cover material A plant-mix or road-mix job on which no seal coat with cover material is used, must be designed with the proper type of aggregate and bitumen content to provide a rough textured "non-skid" finish In the early stages of this "non-skid" surface development, a very rough finish was secured by using aggregate and rock chips as large as 1 to 1½ inches in size Anderson and Wright reported that the tire wear on such a surface was 81 percent greater than on a portland cement concrete surface of the type which they tested In the skid tests reported by Moyer in 1933, those "non-skid" bituminous surfaces showed coefficients of friction lower than on surfaces with a finer surface texture, which can best be described as having a "sandpaper" finish, such as the sandstone rock asphalt surface tested in Indiana This surface and the asphaltic concrete surface, which had sand and ¼-inch quartzite chips for cover material, provided the highest coefficient of friction of the surfaces tested in the wet condition It was evident from the skid tests that a "sandpaper" finish or a finish obtained through the use of fine sharp aggregate with no excess bitumen provided the intimate contact with the tire necessary to obtain a high coefficient of friction

Since no information was available on differences in tire wear caused by variations in types of surface finish on bituminous pavements, the tests covered in this report were planned to determine whether or not the surfaces with the highest coefficients of friction also caused the greatest tire wear Particularly was it desirable to determine the tire wear characteristics on the course-textured "non-skid" type, the "sandpaper" finish, and the smooth glazed finish types of surfaces The need for providing a safe surface with the least amount of tire wear should be apparent

DESCRIPTION OF EQUIPMENT AND TEST METHODS

The test car is a six cylinder, 1932 Studebaker coupe Details of the car, its engine and operating characteristics are described in a paper presented at the Fourteenth Annual Meeting of the Highway Research Board[7] It is equipped

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[5] "Automobile Operating Costs and Mileage Studies" by Robley Winfrey Bulletin 106, Iowa Engineering Experiment Station, 1931

[6] "Statistics of Motor Truck Operation in Iowa" by Robley Winfrey Bulletin 114, Iowa Engineering Experiment Station, 1933

[7] "Motor Vehicle Power Requirements on Highway Grades" by R A Moyer Proc Highway Research Board, Vol 14 (1934)

with 5 50 by 18-inch, four-ply, balloon tires Before the tests were started the engine was inspected and tuned, and the wheel alignment, both front and rear, was adjusted to eliminate erratic wear from this source In making the tests 16,323 miles were traveled The motor was checked and adjusted at 11,800 miles and a new set of spark plugs installed The four tires were identified by the manufacturer's serial numbers Prior to any test runs, break-in runs were made to remove mould filets and other external conditions which might possibly affect tire wear in the early stages of the tests All of the tires were "rotated" for the purpose of maintaining uniform wear on each tire and to preserve a uniform tread condition on all tires Each tire was moved around the car from one wheel position to another, the change being made approximately every thousand miles or at the time when the tire wear measurements were made The order of movement was right front to right rear to left front to left rear to right front, etc The tires were not dismounted from the rims In this way the tire not only changed wheel position, but also alternated direction The total weight of the car including the driver and one observer, or the equivalent weight when an observer was not used, was 3,500 lb of which 1,760 were on the rear and 1,740 on the front wheels The tire pressure was maintained constant at 35 lb, since preliminary tire wear tests indicated that with this pressure the tread wear was fairly uniform

Standard driving speeds of 35 and 55 miles per hour as indicated on the speedometer were adopted Speedometer calibrations indicated that these were actual speeds of 33 and 52 miles per hour The average speeds were from 1 to 4 miles less than the above standard speeds depending upon the length of the test course and the traffic conditions The average speed recorded for each test was computed from stop watch readings for the time that the car was in motion In all of the tests an effort was made to avoid unnecessary braking when stopping or in traffic Stopping the car was accomplished with the motor and an easy application of brakes after the engine resistance had reduced the speed to 15 or 20 miles per hour On curves an attempt was made to drive at a speed which would eliminate all pull on the steering wheel caused by side-skid friction All curves on the test courses permitted operation at 35 miles an hour The smaller wear on curves on the portland cement concrete course due to operation at speeds below 55 miles per hour should tend to reduce the amount of wear shown by this surface This was partly compensated for by the fact that this course was three to four times longer than the other courses and required fewer turns and therefore may have developed slightly higher wear since slightly higher average speeds could be maintained Since the courses were all long and straight, and since more than 95 percent of the travel was on the straightaway at the standard driving speed, the errors from turns may easily be considered to lie within the experimental error which for tire wear tests may be as large as 5 percent

Two 650-mile preliminary test runs were made, one on portland cement concrete and the other on oiled gravel The purpose was to permit the operator to improve this technique in measuring tire wear and in the general conduct of the tests and also to serve as a further "break-in" for the tires which generally have a greater amount of wear when new, possibly due to over-curing and other factors in the manufacturing process which affect the wearing quality of the outer surface of the rubber on new tires The preliminary runs indicated that tire wear is so small on oiled gravel that it seemed desirable to increase the mileage to 1,000 miles between tire wear readings except on the "non-skid" penetration macadam, which was assumed to have a high tire wear The tests were alternated between pavement types to equalize the rate of wear and place the surfaces on a comparable basis with respect to tire wear The portland cement concrete surface was used as a control standard and five series of runs were made on it, not including two cross-country runs which were also largely on portland cement concrete

The depth of the tread at the end of each run was measured with a Federal Dial Depth Gauge, Model 658, graduated to one-thousandth of an inch This is a gravity type gauge which must be held in a vertical position and at the same identical point for successive readings if correct values are to be obtained The movable point on the gauge must rest accurately and freely in the lowest portion of the groove in the tread The base of the gauge must rest firmly on the ribs of the tread with only the weight of the gauge to hold it in place If the support is not uniform, large variations in the readings are likely to result In these tests, measurements were taken at identical and opposite points just inside the riding rib for both the outside and inside rib of each tire at 10 locations on the circumference of the tire There were 20 locations on each tire where tread depth measurements were taken Whenever the seating of the base of the gauge was such that independent check readings at the same point did not agree within two-thousandths of an inch, such readings were thrown out as not being the true readings It was found desirable to allow the tire to cool off over night before the readings were taken because readings taken soon after completing a test run did not check nearly as well as they did when the tire was allowed to cool off and the warping, of the surface of the tire eliminated With all of the precautions taken in making the readings, it is believed that the experimental error from this source did not exceed 5 percent

In the gasoline consumption tests, two portable auxiliary 5-gal cans were mounted in the car in a manner which permitted weighing each can before and after the tests Each can was connected with the main gas line with a simple valve arrangement so that the driver could readily cut the gas line in or out from the auxiliary tanks or from the main tank The gasoline measurements were only made over the test courses The gas from the auxiliary tanks was not shut off to slow down for traffic or to turn around at the end of the test course The gasoline was weighed to the nearest one one-hundredth of a pound on a scale checked with standard weights The weight of the gasoline per gallon was determined by weighing in a standard 5-gal measuring can used to calibrate fuel pumps at service stations

The coefficients of friction were measured on the oiled gravel and the concrete surface using the same equipment used in the 1933 skid tests[4] The coefficients were determined with the tires skidding sideways and straight ahead for both wet and dry conditions Skid tests were not run on the untreated gravel or on the Indiana surfaces because it was felt that the 1933 tests on these surfaces provided the necessary information as far as the coefficients of friction were concerned The "non-skid" penetration surface had a surface texture somewhat similar to that of the Indiana retread tested in 1933 Similar cover stone was used on both surfaces and both had about an equal amount of traffic and wear at the time of test While our estimate on the coefficient of friction of this surface based on the 1933 tests of the Indiana retread may be in error, it is believed that the values are correct within 10 percent

During all of the tests, wet and dry bulb temperatures were taken about three times each half day Records were also taken of wind velocity and wind direction All runs, except the cross-country runs to Indiana and back to Ames, were made in both directions to compensate in part for the effect of wind

TABLE 1

Location and Description of Test Courses

Type of surface	Location	Length (one way), mi	Description
Iowa untreated gravel	County road, route N, from Dayton's Park, N E of Ames, directly east to Marshalltown No curves	30 0	Pit-run gravel, fairly firm with a moderate amount of loose material on surface Gravel smooth and fairly free from sharp edges Surface well maintained—free from corrugations or washboarding
Iowa oiled gravel	Ia 60 north from U S 30 to within 3 mi of Webster City Two easy curves at north end	26 0	Surface reconditioned in 1935 using heavy seal coat and ¼- to ½-inch size limestone chips for cover material Concentration of traffic, combined with hot weather sealed over stone in wheel tracks and formed glazed condition over about 90% of the total length of the test section In cool weather the extent of the glazed condition was greatly reduced
Indiana penetration macadam	Ind 29 between Deer Creek and Burlington Direction north and south No curves	7 5	A penetration macadam surface treated in 1934 with a seal coat and an excess of cover stone ¼- to ¾-inch size providing a rough open textured type of surface The cover stone was a fairly soft limestone with no oil showing on the exposed side The sharp edges were worn smooth at the time of test The surface was smooth riding but the rough open texture caused a rumbling noise typical of this type of treatment
Sandstone rock asphalt	Ind 29 north from Ind 28 to Burlington One slight curve	13 0	Rock asphalt surface treatment placed on an old penetration macadam in heated condition in June 1936 The surface was smooth and had a typical "sandpaper" finish similar to the rock asphalt surface tested in the 1933 skid tests
Iowa portland cement concrete	U S 69 from Ames north to Forest City 10 easy curves, five degress or loss	87 5	Pavement constructed in 1930 and 1931 with a rough textured belt finish There is a definite indication of the polishing effect of traffic in reducing the roughness of the surface texture The pavement has a smooth riding surface

TEST SECTIONS

The locations and descriptions of the test courses are given in Table 1 The test sections were chosen to give the greatest length free from excessive curvature and gradient available in central Iowa They were located in level prairie country with no towns or heavy traffic to interfere with the conduct of the tests at the standard driving speed While the Indiana test courses were notably shorter than those in Iowa they were the longest which we were able to locate in that state or in any of the neighboring states suitable for the tests

RESULTS AND DISCUSSION OF TESTS

Gasoline Consumption—The detailed results of the gasoline consumption tests

TABLE 2

RESULTS OF GASOLINE CONSUMPTION TESTS ON VARIOUS ROAD SURFACES JULY TO OCTOBER 1936

Date	Surface	Direction	Approx road speed, m p h	Actual av speed, m p h	Miles traveled	Gasoline consumption			Temperature, Deg F			Av water temp Deg F	Wind	
						lb[1]	m p g	Range of daily avs, m p g	Av dry	Range of daily avs, dry	Av wet		Av vol, m p h	Direction
July 27–29	Concrete	N-S	35	33 2	483 8	166 32	17 60	17 37–17 91	88 4	78 9– 97 0	65 5	179	5 6	N-NE
July 30–Aug 3	Oil-gravel	N-S	33	32 7	562 4	201 60	16 88	16 63–17 07	87 0	83 2– 90 9	64 2	164	5 0	S
Aug 4–10	Oil-gravel	N-S	33	32 4	688 0	243 59	17 09	16 90–17 40	86 1	84 5– 93 0	66 3	167	4 6	SE/N
Aug 11–15	Concrete	N-S	33	32 8	715 1	242 88	17 81	17 31–18 19	89 0	80 0– 99 5	72 3	165	4 6	SE
Aug 17–19	Concrete	N-S	52	50 1	659 7	280 06	14 25	13 93–14 44	88 3	80 3– 96 0	74 4	173	6 9	S/N
Aug 20–24	Oil-gravel	N-S	52	50 1	840 0	362 36	14 02	13 91–14 20	92 4	86 8–100 4	75 7	179	6 1	S/NW
Aug 25–29	Untreated Gravel	E-W	33	32 4	767 4	287 15	16 17	15 80–16 40	84 0	67 8– 93 3	69 8	171	7 6	NW/SE
Sept 1–9	Untreated Gravel	E-W	50	46 1	842 7	384 05	13 28	12 40–13 60	78 0	73 3– 83 8	68 4	164	5 4	SE
Sept 10–17	Oil-gravel	N-S	52	49 0	774 9	330 27	14 19	14 12–14 26	77 6	62 5– 91 0	65 9	166	9 3	S/N
Sept 18–22	Concrete	N-S	52	50 1	771 9	325 21	14 36	14 06–14 53	73 8	66 3– 84 6	62 7	159	6 4	SE/SW
Sept 25–Oct 1[2]	Oil-gravel	N-S	52	49 4	796 6	341 35	14 19	14 07–14 30	63 9	60 8– 69 3	54.0	154	3 2	S/N
Oct 3–4[3]	Concrete	N-S	52	51 0	299 8	123 04	14 81	14 68–14 93	64 9	61 7– 68 2	59.1	153	5 0	S
Oct 5–6	Cross-country	S-E	52	46 9	294 2	128 11	13 96		73 4	71 5– 75 3	67 5	158	4 3	SW
Oct 7–10	Rock asphalt	N-S	33	33 0	631 0	218 81	17 53	17 02–17 96	67 4	66 3– 68 5	66 0	150	4 7	NE/SE
Oct 11–13	Rock asphalt	N-S	52	49 1	637 9	274 65	14 12	13 41–14 69	61 1	56 0– 67 3	53 8	147	8 0	W
Oct 14–16	Penetration macadam	N-S	52	48 8	538 6	228 27	14 35	14 26–14 44	69 1	64 8– 73 5	61 3	155	3 9	S
Oct 17–19	Penetration macadam	N-S	35	33 4	583 5	209 54	16 93	16 30–17 51	59 5	46 7– 72 0	52 2	146	10 1	NW/SW
Oct 24–25	Cross-country	W-N	52	46 7	329 7	146 24	13 71		50 8		44 5	140	4–12	SW-N

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[1] Weight of gasoline = 6 05 lb per gal

[2] Starting with this period weight of gasoline = 6 08 lb per gal

Motor tune-up, new spark plugs

are given in Table 2 The weather for the most part was exceptionally favorable for the tests Only during the fall did rain and wind interfere All tests were run on dry surfaces and on days on which there was no strong cross wind The lower temperatures and the greater range in temperatures prevailing during the Indiana tests offer a possible explanation for the wider range in gasoline consumption observed In general, the most significant feature of the gasoline consumption tests was the remarkable consistency obtained The range in the values for gasoline mileage rarely exceeded 0 5 mile per gallon In fact, in the tests on the oiled gravel surface during the week of September 10 to 17, the gasoline mileage ranged only from 14 12 to 14 26 miles per gallon in 775 miles

The results of the gasoline consumption tests are shown graphically in Fig 1 and on a relative basis in Table 3, using portland cement concrete as the reference surface with a gasoline consumption index of 100 It is significant that relative values for gasoline consumption on the various surfaces change only slightly if the values obtained at speeds of 33 miles per hour are compared with those at 55 miles per hour Furthermore it is interesting to note that the fuel consumption varies inversely with initial cost of surface That is, the lowest fuel consumption was obtained on portland cement concrete, followed by rock asphalt, penetration macadam, oiled gravel and finally the untreated gravel with a relative index of 110 at 33 miles per hour and 108 at 52 miles per hour It should be mentioned that the tests on this particular gravel road represent just about the most favorable values obtainable on an untreated gravel surface Tests when the surface is covered with a greater amount of loose gravel, is badly washboarded, or is soft and wet after heavy rains, would show considerably greater fuel consumption than those reported in these tests

In Fig 2 gasoline consumption data for tests run on a portland cement concrete course one mile in length are compared with the results obtained on the long test course It should be noted that there is very good agreement in the

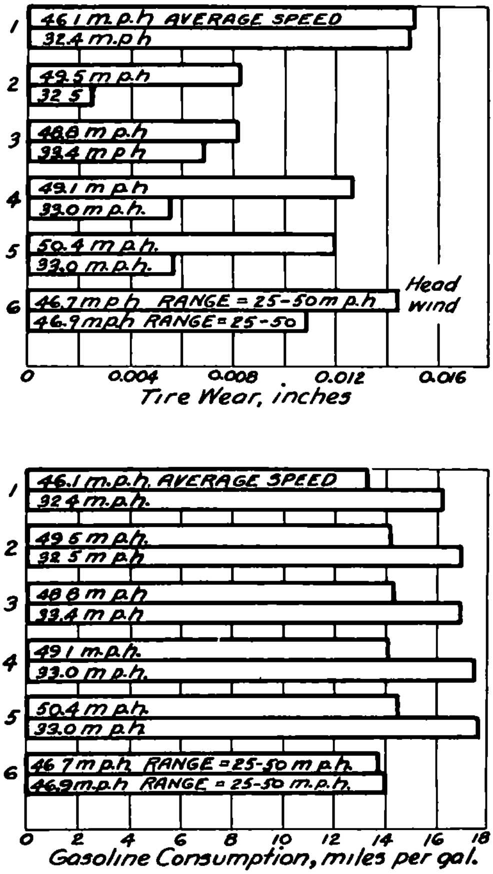

Figure 1 Results of tire wear tests (above) and gasoline tests (below) on various road surfaces. July to October 1936

1. Iowa untreated gravel.
2. Iowa oiled gravel.
3. Ind. penetration macadam.
4. Sandstone rock asphalt.
5. Iowa portland cement concrete.
6. Cross-country 90 per cent portland cement concrete.

results The method and equipment used on the one mile test course were the same as described in the 1934 report [7] The fuel was measured in accurately calibrated glass tubes with a capacity of about 0 1 gal Individual readings could be taken to the nearest 0 0002 gal The results of these tests indicate that if a one-mile course can be located which is typical of the surface to be tested, it is possible to obtain as accurate an index of the fuel consumption characteristics on a one-mile test course as on a longer one

TABLE 3

Effect of Surface on Gasoline Consumption

Type of surface	Gas consumption m p g		Gas consumption index		
	33 m p h	52 m p h	33 m p h	52 m p h	52 m p h *
Iowa portland cement concrete	17 71	14 30	100	100	124
(1) After motor tune-up, etc		14 81		97	120
Sandstone rock asphalt	17 53	14 12	101	101	124
Indiana penetration macadam	16 93	14 35	105	100	118
Iowa oiled gravel					
(1) Hot weather condition	17 09	14 02	104	102	122
(2) Cool weather condition		14 19		101	120
Iowa untreated gravel	16 17	13 28	110	108	122

* Based on gasoline index of 100 for 33 m p h on each surface

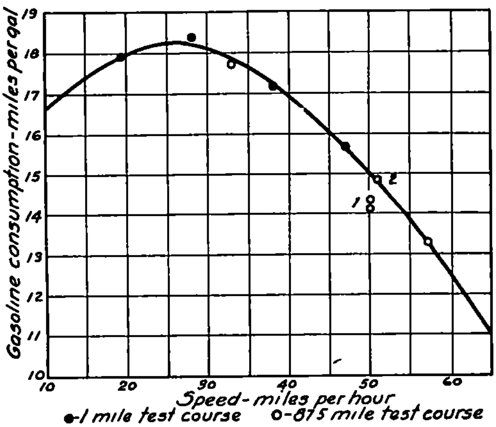

Figure 2 Results of gasoline consumption obtained on a 1-mile portland cement concrete test course compared with results on an 87 5-mile test course (1) At end of 800 miles of test (2) After motor tune up and new spark plugs.

The results of these tests indicated that flexibility of surface is a factor in fuel consumption The Iowa oiled gravel provided a surface which was very nearly the equal of the portland cement concrete as far as the smoothness of the ride was concerned, but apparently the extra force required to flex the surface of the oiled gravel raised the gasoline consumption by the 4 percent shown in Table 3

In continuing this study it is proposed to make runs during cold weather on the oiled gravel and the portland cement concrete surfaces It is reasonable to expect that as the asphalt becomes harder and the surface mat stiffer, the differences in the test values for the two surfaces will decrease

This effect of speed on fuel consumption was emphasized in Moyer's and in Winfrey's reports in 1934[7] but it should be reemphasized in this report In Table 3 a gasoline consumption index is given for all surfaces at 52 miles per hour based on an index of 100 for the consumption at 33 miles an hour, and also for both speeds relative to portland cement concrete The relative change was fairly constant for all surfaces averaging 22 percent for the portland cement concrete and 22 percent for the untreated gravel

When comparing the effects of speed with the smaller effects due to type of surface, the differences in fuel consumption on the various surfaces are no longer significant Only on such surfaces as untreated gravel and dirt are the possible savings great enough to justify large expenditures to improve the surface Of course, the speeds at which the tests were run, 33 miles per hour and 52 miles per hour, were chosen arbitrarily and it should be apparent from Fig 2 that the variation in gasoline consumption will increase or decrease at speeds beyond 30 miles per hour practically in proportion to the increase in the speed differences The highway engineer has no control over these differences and our present knowledge of characteristics of gasoline and Diesel motors indicates that while these differences may be minimized in the future by such devices as the over-drive or a mechanism providing a wide variation in gear ratios, the differences will probably never be eliminated The driver should be educated to the fact that high speed means increased cost of operation and that he should drive at that speed at which he can maintain a reasonable balance between cost of operation and the value of the saving in time resulting from operating at the higher speed

Oil Consumption —Only general observations were made in determining oil consumption No attempt was made to determine the extent of dilution of the oil or similar effects which should be taken into account if an accurate determination of oil consumption were to be made Again the outstanding difference noted was in the effect of speed and not in the effect of the road surface The oil was changed every 1,000 miles and additions were made whenever the oil in the crank case was not up to the "full" mark In the 33-mile an hour tests totaling 6,582 miles, 41 quarts of oil were used involving six changes of 6 quarts each and the addition of 5 extra quarts, or about ¾ quart extra per 1,000 miles There were several 1,000-mile runs at 33 miles per hour on which no oil was added In the 52-mile per hour tests totaling 10,074 miles, 90 quarts of oil were used, involving 9 changes at 6 quarts each, leaving 36 quarts to be added or 3 57 extra each 1,000 miles The extra oil consumption for this increase in speed was, therefore, about 5 times that used at the 33 miles per hour speed The total oil consumption was about 60 percent greater at 52 than at 33 miles per hour

Tire Wear Tests —The detailed results of the tire wear tests are given in Table 4 The results of the California tire wear tests on portland cement concrete and "non-skid" asphaltic concrete made by Anderson and Wright in 1930 are given in Table 5 The results of the Iowa and Indiana tests are compared with the California tests in Table 6 A study of these data shows that the wear on the Iowa portland cement concrete at 33 miles per hour was 73 percent greater than that obtained on the California portland cement concrete where tests were run at 40 miles per hour This difference may be due to actual differences in the surface roughness and in the tires used in the tests The belt finish on Iowa surfaces since 1930 is noticeably rougher than the finish given to portland cement concrete surfaces previous to 1930 The close-up photograph of the California portland cement concrete surface given in the Anderson and Wright report seems to indicate that this pavement, which was built some time before 1930, did not have the roughened surface with which the newer types of portland cement concrete roads are built Computed tire mileages based on the average tread depth of the tires and the life of the tread are given in Table 7 These tire tread mileages seem to agree fairly well with the experience of car operators and tire dealers who have been consulted

The two surfaces which gave the most consistent results were portland cement concrete and sandstone rock asphalt Both of these surfaces have a uniformly smooth, fine surface texture It is interesting to note that the wear on these surfaces was very nearly the same The effect of increase in speed was quite marked, the wear on both surfaces being approximately 2 7 times as great at 52 miles an hour as at 33 miles an hour The wear at 33 miles an hour was less on the portland cement concrete than on any of the other surfaces tested except the oiled gravel which had a seal coat of asphalt At 52 miles an hour the rela-

TABLE 4

RESULTS OF TIRE WEAR TESTS ON VARIOUS ROAD SURFACES, JULY TO OCTOBER 1936

Surface, (in order of test)	Approx road speed, m p h	Tire wear, inches				Average wear, inches	Miles traveled	Unit wear per 1000 miles
		Tire number						
		1309	1509	6409	6309			
Ia portland cement concrete	33	0 0092	0 0033	0 0070	0 0049	0 0061	647	0 0094
Ia oil-gravel	33	0 0051	0 0044	0 0015	0 0032	0 0035	657	0 0051
Ia oil-gravel	33	0 0017	0 0041	0 0042	0 0042	0 0036	1,082	0 0025
Ia portland cement concrete	33	0 0060	0 0069	0 0062	0 0040	0 0058	1,012	0 0057
Ia portland cement concrete	52	0 0101	0 0063	0 0215	0 0137	0 0129	1,058	0 0125
Ia oil-gravel	52	0 0118	0 0085	0 0013	0 0022	0 0062	1,159	0 0044
Ia untreated gravel	33	0 0164	0 0122	0 0169	0 0170	0 0156	1,042	0 0150
Ia untreated gravel	52	0 0211	0 0200	0 0101	0 0093	0 0152	1,006	0 0151
Ia oil-gravel	52	0 0070	0 0063	0 0170	0 0115	0 0105	1,178	0 0085
Ia portland cement concrete	52	0 0220	0 0126	0 0049	0 0062	0 0116	1,027	0 0115
Ia oil-gravel	52	0 0043	0 0071	0 0120	0 0165	0 0100	1,160	0 0081
Cross-country	45	0 0136	0 0205	0 0041	0 0022	0 0101	930	0 0109
Sandstone rock asphalt	33	0 0047	0 0052	0 0068	0 0070	0 0058	1,032	0 0056
Sandstone rock asphalt	52	0 0228	0 0137	0 0043	0 0080	0 0126	1,020	0 0127
Ind penetration macadam	52	0 0035	0 0042	0 0108	0 0080	0 0066	755	0 0082
Ind penetration macadam	33	0 0055	0 0100	0 0045	0 0023	0 0056	753	0 0069
Cross-country	45	0 0058	0 0045	0 0121	0 0083	0 0076	530	0 0145
Other wear	52	0 0034	0 0037	0 0037	0 0018	0 0032	275	
Total miles							16,323	

TABLE 5

RESULTS OF CALIFORNIA TIRE WEAR TESTS, AS REPORTED IN TABLE VII, "FIELD METHODS FOR MEASURING TIRE WEAR" BY A A ANDERSON AND H B WRIGHT, PROCEEDINGS, HIGHWAY RESEARCH BOARD, VOL 11, 1931

Test run numbers	Type of pavement	Total miles[1]	Total depth wear loss, inches[2]	Depth wear loss, inches per 1000 mi	Wear index[3]
C_3, C_6, C_8	California portland cement concrete	3,088 6	0 01145	0 0037	1 00
NS_4, NS_5, NS_7	Non-skid asphaltic concrete	3,523 3	0 02350	0 0067	1 81

[1] Average speed = 40 m p h

[2] Average of rear wheels only

[3] Average wear on P C concrete given index of 1 00

tive wear for the various surfaces was considerably different than at 33 miles per hour A possible explanation for the greater increase in wear obtained at the higher speed on the portland cement concrete, rock asphalt, and oiled gravel is that the smoothness and fine texture of these surfaces permitted more continual and intimate contact of the tires with the surface, whereas on the untreated gravel and penetration macadam, continual and intimate contact of the tires with the surface was not obtained. It should be noted that the stone in the "non-skid" surface of the penetration macadam was a fairly soft limestone, the edges of which had been worn off by several years of traffic It is reasonable to believe that if a much harder aggregate such as a trap, quartzite, or chert were used, the tire wear would have been greatly increased In the tests by

TABLE 6

Type of surface	Condition of surface	Approx road speed, m p h	Miles traveled	Depth wear loss, inches per 1000 mi [1]	Wear index[2]	
					Iowa base	Cal base
Ia untreated gravel	Pit-run gravel, some loose material on surface	52	1,006	0 0181	2 83	4 89
		33	1,042	0 0163	2 55	4 41
Ia oiled gravel		52	1,159	0 0091	1 42	2 46
Hot weather	Excess oil, soft	33	1,082	0 0040	0 63	1 08
Cool weather	Hard, firm seal, no excess oil	52	2,338	0 0128	2 00	3 46
		33				
Ind penetration macadam	No seal coat, soft aggregate, non-skid	52	755	0 0127	1 98	3 43
		33	753	0 0105	1 64	2 84
Sandstone rock asphalt	"Sandpaper" finish	52	1,020	0 0185	2 89	5 00
		33	1,032	0 0070	1 09	1 89
Ia P C concrete	Belt finish	52	2,085	0 0173	2 70	4 68
		33	1,012	0 0064	1 00	1 73

[1] Rear wheels only

[2] Average wear on portland cement concrete, at 33 m p h given index of 1 00

TABLE 7

COMPUTED TIRE MILEAGE ON VARIOUS ROAD SURFACES BASED ON TESTS OF TIRES WITH AN AVERAGE TREAD DEPTH OF 0 288 INCHES

Surface	Actual mileage Speed constant, no extra braking		Estimated mileage braking, driving on curves, etc , (35% additional wear)	
	33 m p h	52 m p h	33 m p h	52 m p h
Ia untreated gravel	19,200	19,050	12,500	12,400
Ia oiled-gravel				
(a) Hot weather	115,200	65,450	74,900	42,550
(b) Cool weather		34,700		22,550
Ind penetration macadam	41,750	35,100	27,150	22,800
Sandstone rock asphalt	51,450	22,700	33,450	14,750
Ia portland cement concrete	50,550	24,000	32,850	15,600

McNown[1] and Waller[2] large variations in tire wear were obtained on the gravel and macadam surfaces, largely because of the variations in the sharpness and hardness of the aggregate

The results of the tests on the untreated gravel show wear over 2½ times as great as that obtained on the portland cement concrete at 33 miles per hour but at 52 miles an hour the wear on the gravel was only about 25 percent greater than on the concrete for the same speed Also, on the untreated gravel, the wear at 33 miles an hour on the rear tires was only slightly greater than on the front tires, while at 52 miles an hour the wear was approximately twice as great on the rear as on the front tires (Table 8) In the tests by McNown and Waller, the wear on hard firm surfaces such as portland cement concrete was approximately twice as great on the rear tires as on the front tires while on gravel and loose macadam surfaces the wear was very nearly the same front and rear Since their tests were run at the low speeds of 25 to 35 miles an hour, the results of these tests at 33 miles an hour should and do compare favorably with their results

A reasonable explanation for the wear characteristics of the front and rear tires is that on the gravel road at the lower speeds the front wheels prepare a path and push aside some of the loose gravel providing a smoother surface for the rear wheels Also the front wheels in "pushing" through the loose gravel probably slip as much backward as the rear wheels spin or slip forward under the driving action of the motor At the higher speed of 52 miles per hour the wear on the front wheels was actually less than it had been at 33 miles per hour, indicating that there was less of the plowing action and less slippage on the front wheels at the higher speed At

TABLE 8

DISTRIBUTION OF TIRE WEAR ON VARIOUS SURFACES FOR EACH WHEEL POSITION

Surface, (in order of test)	Approx road speed, m p h	Tire wear, inches				Av wear, inches	Miles traveled	Unit wear per 1000 mi
		Right front	Right rear	Left front	Left rear			
Ia portland cement concrete	33	0 0092	0 0070	0 0033	0 0049	0 0061	647	0 0094
Ia oil-gravel	33	0 0032	0 0051	0 0015	0 0044	0 0035	657	0 0051
Ia oil-gravel	33	0 0041	0 0042	0 0017	0 0042	0 0036	1,082	0 0025
Ia portland cement concrete	33	0 0062	0 0069	0 0040	0 0060	0 0058	1,012	0 0057
Ia portland cement concrete	52	0 0101	0 0215	0 0063	0 0137	0 0129	1,058	0 0125
Ia oil-gravel	52	0 0022	0 0118	0 0013	0 0085	0 0062	1,159	0 0044
Ia untreated gravel	33	0 0122	0 0170	0 0164	0 0169	0 0156	1,042	0 0150
Ia untreated gravel	52	0 0101	0 0200	0 0093	0 0211	0 0152	1,006	0 0151
Ia oil-gravel	52	0 0070	0 0170	0 0063	0 0115	0 0105	1,178	0 0085
Ia portland cement concrete	52	0 0062	0 0220	0 0049	0 0126	0 0116	1,027	0 0115
Ia oil-gravel	52	0 0071	0 0165	0 0043	0 0120	0 0100	1,160	0 0081
Cross-country	45	0 0041	0 0205	0 0022	0 0136	0 0101	930	0 0109
Sandstone rock asphalt	33	0 0047	0 0068	0 0052	0 0070	0 0058	1,032	0 0056
Sandstone rock asphalt	52	0 0080	0 0228	0 0043	0 0137	0 0126	1,020	0 0127
Ind penetration macadam	52	0 0042	0 0080	0 0035	0 0108	0 0066	755	0 0082
Ind penetration macadam	33	0 0045	0 0100	0 0023	0 0055	0 0056	753	0 0069
Cross-country	45	0 0058	0 0121	0 0045	0 0083	0 0076	530	0 0145
Other wear	52	0 0037	0 0037	0 0018	0 0034	0 0032	275	
Total miles							16,323	

the same time the wear on the rear wheels was higher at 52 miles an hour than at 33 miles an hour, because the tires had to dig into the surface to develop the higher tractive force required at this speed. The net effect of these changes caused an average tire wear on the untreated gravel at 52 miles per hour which was only about 25 percent greater than that on the portland cement concrete at the same speed

It might appear that tire wear on untreated gravel at the higher speeds was not excessive when compared with other surfaces A few general observations which are not revealed by the tread depth measurements should be made to amplify the results In the first place, in all of the 16,300 miles of tests, there were only two punctures, both of which were caused by nails picked up on the untreated gravel Also, the nature of the wear on the untreated gravel was quite different than that on the hard firm surfaces The wear was more spotty and there was considerable cutting, pitting, and bruising of the surface of the tread, which could not be completely measured The effect of this pitting was only eliminated after running 1,178 miles on the oiled gravel at 52 miles an hour and it is this condition of the tires at the beginning of the latter tests which explains in part why the wear on the oiled gravel was about 80 percent higher than it had been on the previous test at that speed In view of these facts, the wear on the untreated gravel should have been 10 to 20 percent greater than was shown by tread depth measurements

While some of the wear on the oiled gravel was due to the pitting of the tires caused by the untreated gravel, the tests on the same surface after a check test had been run on portland cement concrete revealed an increase in tire wear on the oiled gravel very nearly as large as in the previous test Since the tire wear on the portland cement concrete checked very nearly the wear previously obtained on this surface and since the tire tread appeared in every way to have returned to the condition it had before the tests on the untreated gravel were run, this increase in wear on the oiled gravel could only be attributed to the condition of the surface and the change in temperature The previous oiled gravel tests for which a tire wear of 0 0044 inch per thousand miles was observed were run during hot weather after the surface had sealed over with oil in the wheel tracks However, in the month of cool weather intervening between the tests, the bleeding disappeared and traffic wore off some of the excess asphalt At the same time since this sealed over condition existed only in the wheel tracks, there was some opportunity for traffic to bring some gritty particles onto the surface The asphalt also was much harder than it had previously been This appears to be a reasonable explanation for the higher wear during the cooler weather It is proposed to continue running a limited number of tire wear tests on the oiled gravel and on the portland cement concrete during the winter months to determine possible variations in the surface and in the tires which may contribute to a better understanding of the effect of the surface, of the tire, and of variations in temperature on tire wear

Figure 1 indicates more clearly the wide variations in tire wear on the various surfaces and the effect of speed on tire wear The variations in fuel mileage for these same conditions are small indeed when compared with the variations in tire wear While it is true that the fuel costs per mile are 2 to 3 times as great as the tire costs per mile, these data indicate that variations in tire wear may have the same total effect on the variable costs in the operation of a motor vehicle as the variations in gasoline required on the various surfaces for the various speeds

The accumulated tire wear showing the total wear for the four tires at each of the four wheel positions (Fig 3) is a matter of interest to the engineer as well as to the motorist The wear on the right front is shown to be 18 5 per cent of the total, on the right rear 38 0 per cent, on the left front 14 0 per cent and on the left rear 29 5 per cent In all of the tests the wear on the rear tires has been slightly more than twice that on the front tires, and the wear has been about 30 per cent more on the right side than on the left side There seems to be no way in which the highway engineer can change the wear ratio front to rear on hard surfaces, but he can reduce excessive wear on the right side by holding the crown of the road to a minimum Of course, rotation of tires to the different wheel positions has demonstrated its value in providing uniform tread wear on all wheels While the 16,300 miles of test showed a tire wear of from 0 08 inch on the left front to a wear of 0 23 inch on the right rear, or an amount of wear which was almost 3 times as great, the actual average wear on the four tires was only 0 15 inch out of a total average tread depth of 0 288 inch and the greatest difference in wear on any individual tire at the end of the tests did not vary by more than 0 02 from this average depth It is not necessary that the tires be rotated every 1,000 miles to maintain a uniform tread wear condition but for the best results it should be done every 3,000 to 5,000 miles

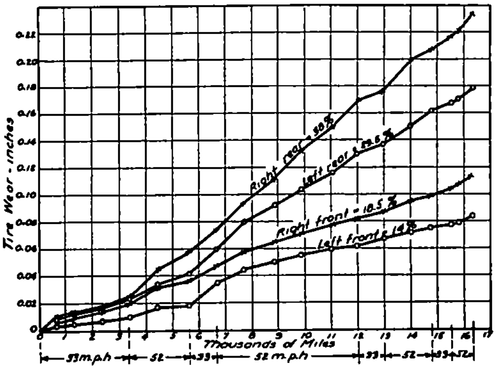

Figure 3 Accumulated tire wear on five road surfaces in Iowa and Indiana tested at approximate road speeds of 33 and 52 m p h July to October 1936.

The variations in tire wear for the various surfaces at the two speeds used in these tests are well illustrated by the data in Table 7 showing the computed tire mileage or life of the tread based on the results obtained in these tests. Since great care was exercised in these tests to maintain constant speeds and to avoid extra wear caused by side-skid friction on curves or the extra friction caused by braking, this tire mileage is higher than that which can be obtained in actual service Figure 4 shows typical results of tire wear on one type of surface for a car operated with traffic at road speeds of 50 to 60 miles per hour (A) with no extra braking, and (B) with extra braking every 10 miles bringing the car to a complete stop On the basis of these results it seemed reasonable to add 35 percent wear to allow for extra braking and driving on curves at speeds which cause extra tire wear The resulting mileages seem to be reasonable and to compare favorably with the experience of car owners and tire dealers for tires of the type used in these tests

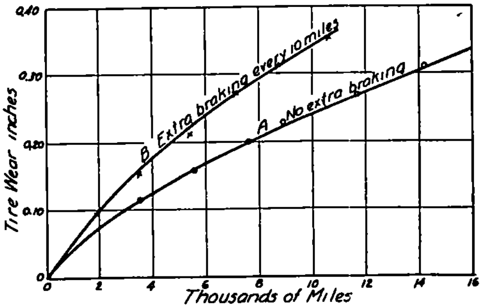

Figure 4 Typical tire wear curves, (A) with no extra braking and (B) with extra braking every ten miles

Coefficients of Friction —The results of the friction tests in 1936 on the surfaces involved in the tire wear tests, and of similar surfaces tested in 1933 are shown in Figs 5 and 6 The 1936 tests on the portland cement concrete checked fairly closely the results obtained in 1933 The slight decreases in the coefficients obtained this year indicate the polishing effect of traffic on this surface since the previous tests were run The tests on the glazed-over sections of the oiled gravel surface clearly indicated the slippery condition of this surface Even in the dry tests on these sections the coefficients were reduced enough to shorten greatly the distance in which a car could be stopped On the sections on this surface on which there was no excess asphalt, the coefficients in the straight skid tests were raised to values slightly lower than those obtained in the 1936 portland cement concrete tests, and in the side skid tests to values appreciably higher than those obtained in the 1936 portland cement concrete tests

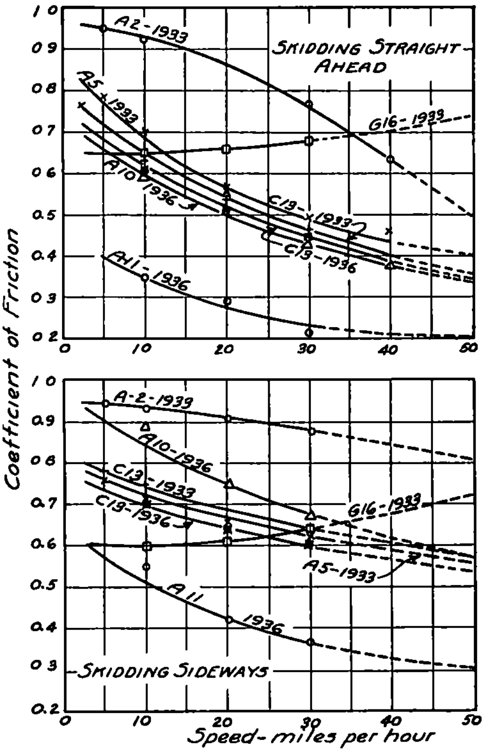

Figure 5. Coefficients of friction of wet surfaces with new tread tires, tested for tire wear and gasoline consumption in Iowa and Indiana

A-2—Rock asphalt
A-5—Penetration macadam type
A-10—Oil-gravel, no excess oil
A-11—Oil-gravel, excess oil
C-13—Portland cement concrete
G-16—Ia untreated gravel

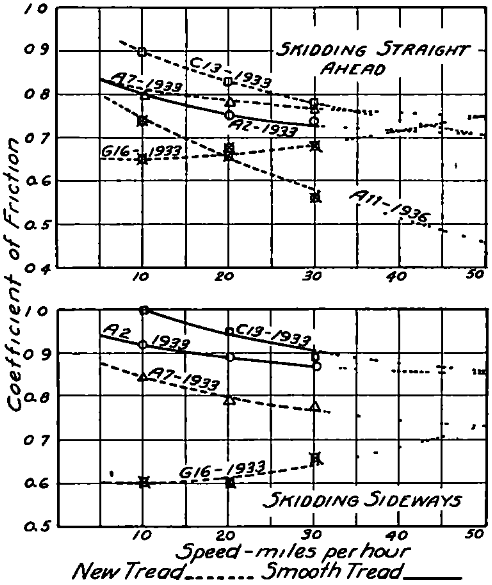

Figure 6. Coefficients of friction of dry surfaces tested for tire wear and gasoline consumption in Iowa and Indiana.

A-2—Rock asphalt
A-7—Oil-gravel, no excess oil
A-11—Oil-gravel, excess oil
C-13—Portland cement concrete
G-16—Ia. untreated gravel

Penetration macadam, oiled gravel with no excess oil, and portland cement concrete appear to have similar skidding characteristics in the wet condition and occupy a middle ground as far as the coefficients of friction are concerned The sandstone rock asphalt surface stands out in this study as a surface with exceptionally high coefficients, and the oiled gravel with the excess oil as a surface with dangerously low coefficients when wet In attempting to correlate these results with the tire wear tests, it should be noted that the oiled gravel with the excess oil provided the least wear, only one-half to one-third that obtained on the portland cement concrete, the rock asphalt surface with the highest coefficient provided wear only slightly higher than that obtained on the portland cement concrete, the "non-skid" penetration macadam provided coefficients about the same as portland cement concrete with an average wear which was somewhat lower than that obtained on the portland cement concrete, the untreated gravel surface with moderately high coefficients in the straight skid tests and low coefficients when skidding sideways provided the greatest tire wear obtained on any surface These tests indicate that surfaces with a "sandpaper" finish of the rock asphalt type provide considerable extra protection against skidding at no appreciable extra expense in tire wear Coarse open textured surfaces such as the penetration macadam offer less resistance to skidding than the surfaces with a "sandpaper" finish and no great advantage if any in tire wear It is the writers' opinion that tire wear tests on the penetration macadam which included extra braking would show a large relative increase when compared with the results obtained in similar tests on hard surfaces with a fine textured surface, because in the straight skid tests on surfaces of the open textured type, it was observed that the beads and edges of the tread were badly cut and scuffed due to the tearing action of the coarser rock particles It appears reasonable to believe that a surface which causes the tire to wear off in small rubber particles rather than to scuff off or tear off in large particles should have the least wear under all types of driving and should, according to our test results, have the greatest resistance to skidding

SUMMARY AND CONCLUSIONS

While this report is intended as a progress report and further tests are to be made, the tests appear to be far enough along to warrant the presentation of the following summary and conclusions

1 Gasoline consumption tests in traffic over long test courses provide no new information which cannot be obtained in carefully conducted tests over one- or two-mile courses at a considerable saving in expense

2 The gasoline consumption tests over the long test courses were very consistent in spite of variable temperatures and wind conditions The range in gasoline mileage rarely exceeded 0 5 miles per gallon and in one 775-mile series of tests on oiled gravel, did not exceed 0 14 miles per gallon All tests were run in both directions

3 The best gasoline mileage in these tests was obtained on the portland cement concrete surface followed closely by the rock asphalt, penetration macadam and oiled gravel The untreated gravel gave gasoline mileage approximately 10 percent less than the portland cement concrete

4 The relative change in gasoline mileage caused by operating at 33 and at 52 miles an hour remained fairly constant for all surfaces, the results indicating that mileage was reduced 22 per cent at the higher speed The changes due to speed far outweigh the changes due to type of hard surfaces

5 The extra oil consumption at 52 miles an hour was about 5 times greater than at 33 miles an hour

6 The measurement of tire wear by means of a depth gauge provides an accurate method of determining wear on all types of surfaces except possibly an

untreated gravel in which pitting of the tire reduces the accuracy of the measurements

7 To obtain consistent results 1,000 miles of travel are required between each set of tread wear readings

8 Rotation of tires is necessary to maintain a uniform tread condition

9 Perfect seating of the depth gauge is necessary for accuracy Independent readings which do not check within two one-thousandths of an inch should be thrown out

10 Tire wear measurements may best be taken 10 or more hours after the test runs to eliminate warped surface conditions on the treads

11 The most consistent results in tire wear were obtained on the portland cement concrete and the sandstone rock asphalt, both of which had about the same wear at 33 and at 52 miles an hour

12 The greatest tire wear was obtained on the untreated gravel, the wear at 33 miles per hour being 2 7 times that on the concrete at this speed

13 The wear on the rock asphalt and portland cement concrete at 52 miles per hour was 2 7 times the wear at 33 miles an hour

14 The wear on the untreated gravel was practically the same at 33 and at 52 miles per hour

15 At 33 miles per hour the wear on the rear tires was double that on the front tires on hard surfaces but remained the same on the untreated gravel At 52 miles an hour the wear of the rear tires on all surfaces was about double that of the front tires

16 The only punctures encountered in 16,300 miles of test were two on the 2,000 miles of untreated gravel

17 The tire wear on the oiled gravel in hot weather with excess asphalt glazed over its surface was one-half to one-third that obtained on the portland cement concrete

18 The tire wear on oiled gravel in cool weather was about two-thirds that obtained on the portland cement concrete, the wear on the latter remaining practically unchanged within the temperature range prevailing from July to October

19 Tire wear on the right side was 30 percent greater than on the left side This was largely due to the effect of crown

20 On the basis of the total wear in all of the tests the least wear was obtained on the left front wheel and the greatest wear on the right rear wheel, the latter being three times the former Our tests demonstrated that rotation of the tires every 3,000 to 5,000 miles will tend to balance this large spread in wear

21 The estimated mileages for the life of the tread on these tires in actual service based on the results of these tests at 52 miles an hour were computed to be 12,400 miles for untreated gravel, 14,750 for sandstone rock asphalt, 15,600 for portland cement concrete, 22,800 for penetration macadam and 42,550 for the oiled gravel with the excess asphalt on the surface

22 The results obtained in the 1936 skid tests on portland cement concrete checked fairly closely the test values obtained in the 1933 tests

23 The coefficients of friction on the oiled gravel with the excess asphalt were found to be dangerously low when wet and fairly low even in the dry condition

24 In correlating the results of the skid tests and tire wear tests, tire wear on oiled gravel, which had the lowest coefficient, was one-half to one-third that obtained on the portland cement concrete, rock asphalt with the highest coefficient, showed wear only slightly greater than that on the portland cement concrete, the "non-skid" penetration macadam with coefficients about the same as portland cement concrete gave average wear slightly lower than that obtained on portland cement concrete,

the untreated gravel with low coefficients especially in the side-skid tests provided the greatest tire wear

25 The surfaces with a "sandpaper" finish when compared with the coarse open textured types of surfaces, provide considerable extra protection against skidding at no extra expense in tire wear

26 The most important items in the cost of modern highway transportation which are affected by the surface are fuel, tire, and road costs Depreciation and maintenance items, other than extra car washing, tire chains for mud, windshield breakage and extra fender wear from loose gravel are not appreciably affected by the type of road surface Transportation charges for these items can be made the same for all types of surfaces except for the slight corrections noted