small end 10 inches, and diameter of large end 14 14 inches As it was most convenient to set the motors in the draft tube, the condition was approximated in the model and an equal net volume obtained by increasing the diameter of the large end of the draft tube to 15½ inches This increase in size gave equally good results when an obstruction of size and shape corresponding to the motors and to their concrete base was put in the proper position With this draft tube in place it was found that a fan would produce a given air speed with approximately one-half the power input required when the draft tube was not used The effect of spinners, hydraucones, cores, and guide vanes was investigated but none was found to be beneficial

A draft tube 12 feet long with an exit end of 15 feet 6 inches diameter was built on to the original tunnel, making the total length about 50 feet The transition section and the draft tube were built of 20-gage sheet metal fastened to wooden frames and the remainder of the tunnel constructed of matched flooring

Two 55 H P direct current motors are connected directly to the fan by means of suitable flexible couplings, and speed regulation is obtained by a set of resistance grids and by field rheostats

The fan was first set with a blade angle of 35 degrees, but has since been changed to 30 degrees and 30 minutes, due to the maximum power output that was obtained from the motors at an unfavorably low speed

A spring balance for measuring the pull on the car has been made and installed The wind velocity is measured by means of a pitot tube and an inclined manometer In a trial run, the force exerted on a Dodge touring car at a wind velocity of 36 miles per hour was about 90 pounds, which represents a power consumption of over 8½ H P This figure is approximate as the platform resistance is not subtracted A device for lifting the car off the platform in order to obtain the effect of the wind on the platform itself has been perfected

The following investigations remain to be made

1 To determine the effect of the platform on the total pull for each type of car
2 To determine the error due to the fact that the wheels are stationary instead of turning
3 To determine the wind resistance of all available types of cars
4 To derive an empirical formula for the wind resistance in terms of the projected area of the car and its velocity

E

INVESTIGATION OF TIRE WEAR

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This is the second progress report on Cooperative Test between the University of Kansas and the U S Bureau of Public Roads to determine the relation of road surface to tire wear

The first report made in the fall of 1923 was a discussion on the general aspects of the problem, a resumé of the work previously done, and a description of the apparatus and methods proposed for the conduct of the work was published in Bulletin No 43 of the National Research Council The work was continued through the months of July and August of this year by Professors W C McNown and G W Bradshaw To date, the total time spent on the work by these two men has been four and one-half months

Restatement of the problem —The problem is to determine the relative effect of various standard types of road surfaces upon the wear of automobile tires At the inception of the project it seemed practical to adopt what might be termed standard equipment, that is, actual tires and vehicle equipment rather than models, or special devices, to be used in seeking determination of physical values The work was prosecuted in accordance with this plan and although results were difficult to get, and many times unsatisfactory, it appears that the course followed was a wise one

The factors which influence tire wear may be classified into two groups

1 Those connected with, and affected by, the road
2 Those associated with the tire and the vehicle.

In the first class are

(a) Condition of road surface existing upon any small unit area, minor roughness possibly measured by some factor such as coefficient of kinetic friction
(b) Condition of road surface taken over a distance, trueness of longitudinal contour, as evidenced by waves in bituminous surfaces and rhythmic corrugations in gravel roads

The second condition does not exist in the ideal bituminous or gravel road and it does seriously affect tire wear, but its effect may be eliminated, and a study of tire wear should show its proper relation in this investigation.

In the second class of factors there are

(a) Quality of the tire
(b) Inflation of the tire
(c) Alignment of wheels.
(d) Traction
(e) Weight on tire
(f) Speed of vehicle

To obtain perfect data for the solution of the problem, these factors should be held in constant relation, but such a condition is impossible There are inevitable variations of a moderate character in them, and the differences are great when the quality, or individual characteristics, of the various tires are taken into consideration. When one type, make, and size of tire is used, the variations in the individual characteristics are quite marked, although the best method is to use a limited number of tires, collect a large number of data, and use judgment in selecting values for averages It takes much time, expense, and effort to obtain the data, and the difficulties of an early solution are readily discernible.

When preparing for a test on some road surface, we adopt as standard a certain vehicle, tire, inflation, weight on tire, speed, traction, and insure the best possible in the way of alignment, thus securing the means for determining a set of data The unit of measurement was taken as the number of grams loss in weight in a 500-mile run over a given surface In the first report certain difficulties were noted in determining accurately the loss in weight due to wear The results obtained by drying at a low temperature have proved satisfactory

As traction is one of the variables to be controlled, we have used only sections of roads with level or very slight grades Such sections are not always easy to find, and the length of the test sections has been affected To avoid numerous turns, ten-mile sections are desirable, and in only one case have we accepted less than five miles

To expedite the work and to have one full set of tires available while the other was drying to constant weight, we have attempted to use two sets of tires hoping to correlate the data by means of the laboratory

TABLE I

RESULTS OF TIRE WEAR USING LABORATORY APPARATUS

TIRES Kelly-Springfield 32x4, B & B cords
WEIGHT ON TIRES equivalent to that on a rear tire of a Dodge touring car
INFLATION 65 lbs per sq inch
TRACTION 50 lbs per ton

1	2	3	4	5	
Tire No	Date of test	Loss in grams in 500 Miles	Total previous mileage	Total mileage of road wheel	Remarks
1	1923	32 9	0	2000	Tires number 1, 2, 3, and 5 were purchased during July and August in 1923 Tires 6, 7, 8, 9, and 10, were purchased during July and August, 1924 The discrepancy between columns 4 and 5 in the matter of total mileage is due to the fact that some runs were made previously with these tires on a wheel that failed and was replaced by the one now in use
2	1923	34 8	0	500	
3	1923	32 0	0	1000	
4	1923	22 1	0	1500	
5	1923	24 2	1500	0	
1	8- 1-24	12 5	1250	4000	
2	10- 1-24	8 5	2000	6000	
3	7-29-24	22 0	1200	3520	
5	10- 6-24	15 2	3150	6500	
6	7-19-24	27 4	0	2500	
7	7-25-24	20 2	0	3000	
8	9-24-24	10 4	625	5500	
9	9-19-24	18 4	1000	5000	
10	9-13-24	18 3	500	4500	
		Runs using under-inflated tires			
2	10-24-24	36 4	2500		Inflation, 40 lbs per sq in
10	11- 5-24	78 9	1500		Inflation, 35 lbs per sq in

apparatus So far, we do not feel that such correlation has been an entire success, but it is too soon to draw definite conclusions The time element is an important one, and the attempt to work intensively during a few summer months had better be abandoned Hence we are now carrying on certain parts of the work during the academic year

Laboratory work —The description and intended use of the laboratory apparatus was given in full in the first report and no material changes in apparatus or plan have been made The concrete shod wheel stood up well under service for a time, but is now beginning to show signs of weakness and may soon have to be renewed It seems to simulate the ideal concrete road This season we have made eleven five-hundred mile runs on it All tires used on the road have been run over it for five hundred miles at least once The results obtained do not, in all cases, appear to agree with those on the road, and so duplicate runs will be made in these cases

The traction used on the apparatus has been held at 50 pounds per ton This value was taken in the beginning in order to establish one point on the wear-traction curve and it has not seemed wise to change Present plans are to establish other points on this curve before the present wheel fails and a new one, having a different roughness characteristic, has to be put upon the apparatus

Table I gives the results on this part of the work

The road wheel has worn smoother with use to a degree noticeable to the touch This furnishes a possibility of determining the effect of varying degrees of roughness upon the wear of tires In Figure I the wear values in column 3 are plotted against the accumulated mileage

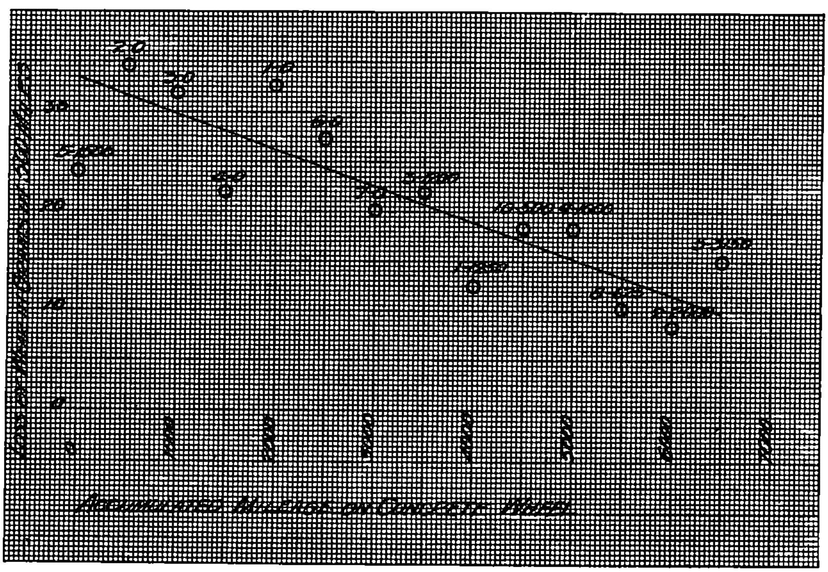

FIGURE 1
Variation in Tire Wear

TABLE II

RESULTS OF TIRE WEAR FROM ROAD WORK

Kind of pavement Number and date of test (1924)	Tire No	Position of tire	Loss in grams in 500-miles	Distance run in miles	Remarks
Concrete		*			
R-1 July 21	1	F-L	25		East from Lawrence, Kansas, on Federal Aid Project No 7, Length, 5 5 miles, width, 18 ft , grade, one hill sufficient to increase traction somewhat Otherwise a flood plain grade Puncture on No 3 replaced with No 5, Surface rather rough About 4-5 of stretch paved with concrete using soft limestone for aggregate and 1-5 using Joplin flint
July 22	2	F-R	40		
July 23	4	R-L	56	512	
July 23	3	R-R	68		
	5	R-R			
Gravel					
R-2 July 27	2	F-L	138		Golden-Belt Highway, near Perry, Kansas Length, 10 miles Flood plain grade, surface good, gravel of uncrushed chert coming from disintegrated limestone, many sharp edges
July 28	1	F-R	134	252	
	4	R-R	192		
	6	R-L	128		
Concrete					
R-3 Aug 8	1	F-L	7		South of St Joseph, Missouri on Missouri Federal Aid Project No 52, length, ten miles, width, 18 ft , level flood plain Two grade crossings causing slowing down Surface contour very good Aggregate medium grade limestone
Aug 9	7	F-R	16	250	
	2	R-R	43		
	6	R-L	16		
Penetration Macadam					
R-4 Aug 19	1	F-L	59		North of Iola, Kansas on Kansas Federal Aid Project No 19, length, 4 5 miles, grade slightly undulating, crown high, width, 16 ft , center pretty well ironed out by traffic giving characteristic tight bituminous surface Outer edges wavy with exposed but not loose aggregate, aggregate Joplin flint chats, very sharp Noticeably rough riding at 25 miles per hour
Aug 20	7	F-R	222		
	8	R-L	77	490	
	5	R-R	343		

Monolithic Brick					
R-5	9	F-L	49		West from Hutchinson, Kansas, on the Hutchinson-Nickerson Road, Kansas Federal Aid Project No 15, length, 10 miles, width, 18 ft , flood plain grade Surface contour good, but not excellent
Aug 26	3	F-R	139	499	
Aug 27	6	R-L	14		
	2	R-R	42		
R-6 Aug 29					An attempt to repeat R-3 for 500 miles instead of 250 Run failed on account of a broken drive shaft at end of 132 miles
Gravel					
R-7 Sept 3	9	F-L	43		Between Webster City and Iowa Falls, Iowa, on Iowa State Primary Highway No 5, length, 12 miles, grade nearly level, some minor undulations not sufficient to increase traction under careful driving Some rhythmic corrugations About what would be typical of a good gravel road not recently planed Material, typical uncrushed glacial drift gravel, such as found in Iowa, Minnesota, and Wisconsin
Sept 4	10	F-R	77	500	
Sept 5	2	R-R	62		
	6	R-L	60		
Concrete					
R-8 Oct 11–12	10	F-R	63		Repeating R-3
	9	F-L	44	491	
	8	R-R	27		
	6	R-L	15		

*F-L equals front left F-R equals front right R-R equals rear right R-L equals rear left in column 5 Beside each point is set the number of the tire and its previous mileage A straight line has been drawn to indicate roughly the variation The law of variation obviously can not be a straight line, but we have not sufficient data to establish anything approximating a law

It is probable that two factors combine to cause the variation indicated by the slope of the line One is the decreasing roughness of the road wheel, and the other the effect of the mileage of the tires upon their wear characteristics The former is the predominating factor, as all of the tires used were riding high upon the "block and button" configurations of the tread

Under-inflation—A series of tests to show the effect of under-inflation has been started, and results are shown in Table I which may be compared with other results using the same tires and standard inflation

Road work—Test runs were made upon concrete, gravel, monolithic brick, and asphaltic macadam for a total mileage of 3,000 miles, and the results have not been satisfying Considered as preliminary runs, they have value as indicating what to do next Perhaps their chief value lies in the indication of certain factors on tire wear, the presence and magnitude of which might be lost sight of in any test devised upon a purely laboratory basis The results of all runs are shown in Table II (Page 26).

Some comment upon the specific results may aid in their interpretation Observing the behavior of individual tires, No 6 gave consistently low values in the various runs except on gravel, but the single run in the laboratory showed wear above the average The laboratory run must be checked Tires No 9 and No 10 gave high values on the road The excessive wear on tire No 3 in R-5 was due to repairs on it after it had been punctured by a piece of broken spring in R-1 As there were not enough tires to make up a set in R-5, it was put on the car

The road runs were made in circuits running up and down a given stretch of road, hence, left-hand tires would always be on the inside and nearer the center of the road It is possible that the rather consistently lower amounts of wear shown on left-hand tires in R–1, R–3, R–5, and R–7 were due to the fact that the pavements were smoother nearer the center With R–4 this was the case, as the outer edge was wavy and had sharp aggregate protruding from the bituminous binder, while the center was somewhat wavy, but well ironed out by the traffic The pavement was narrower and inner wheels running in both directions passed near the center. In this connection, on the Iowa gravel road with its similar inner and outer roughness characteristics, the wear on both sides was about the same for the rear wheels A loose surface was maintained on this road

The ratio of wear on front to rear tires is not clear from the data so far obtained If certain results, which seem to be free from other complications, be taken and averaged, the front tire wear is 56 per cent of the rear wear

Three runs totaling 1,250 miles were made on concrete The pavement used for R–I was noticeably rougher than that used for R–3 and R-8 The failure of R–8 to check R-3 is not explainable

Conclusions—It is believed that certain general conclusions can be made from this preliminary work

1 The difference in the effects of certain high type pavements such as concrete and brick, and probably asphalt, upon tire wear is not great if these pavements are in high-class surface condition

2 Roughness of longitudinal contour causing bounding, acceleration, impact, and deceleration, with its accompanying slippage, has a marked effect upon the wear of tires running with standard inflation

3 Under-inflation is probably the cause of much greater wear than is ordinarily assigned to it, although it can not be said how much this effect is offset by decreased wear due to the lessened amount of bounding and impact

4 A vast amount of tire wear results from various causes not assignable to pavement type And if a great amount of value in tires is dissipated in other ways than in running, properly controlled, over well made surfaces, then care should be taken not to overestimate these values in the solution of problems in highway economics until more data are available

5 Tire wear investigations, using laboratory methods and small-scale devices instead of standard equipment, may give results wholly misleading Relative values may be obtained, but should be used with caution until more is known about the relation between the amount of value actually existing in tires and that used in other ways beside by running properly over first-class pavements such as by stopping and starting, by physical deterioration while standing, running over rough pavements, and abuses such as under-inflation and high speeds

The report of the Committee on Economic Theory of Highway Improvement was discussed by G F Schlessinger, of the Ohio State Highway Department In his discussion, Mr Schlessinger urged all highway departments to comply with the Committee's request for the submission of available statistics The need for accurate records on the life of various types of pavements is recognized so that the method of analyzing the cost of the road as offered by the Committee may be applied

The discussion also dealt with suggestions for additional information in the matters of engineering economics, such as the economic width of pavement, grade crossing elimination, and the effect of the improvement upon property values within a given zone on either side of the road Mr Schlessinger's paper has been published in full in the January issue of Highway Topics

L. E Wooten, of the North Carolina State College, described the tests that are being conducted at that college to determine the tractive resistance of road surfaces by using an electrically propelled vehicle This apparatus makes possible the determination of the total power consumed under operating conditions

The paper on Practical Application of Research in Highway Design, by E W James, of the U S. Bureau of Public Roads, contained a summary of the development of research in the highway field. Mr James emphasized the value of information on the design for concrete and bituminous surfaces. In concluding, Mr. James said, "Although we possess today some information which, owing to incompleteness, we can not use because we are unable to solve our most important problems, the highway designer is nevertheless making use of all the data which he can use, and his work has now reached a point where he can indicate to the investigator definite lines for further study."

Chairman Johnson: We shall now be interested in hearing the report of the Director.