FRICTION OF PNEUMATIC RUBBER TYRES ON SNOW

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The paper describes a new apparatus for determination of the friction of pneumatic rubber tyres on snow at different loads for different inflation pressures. It is found that the friction decreases with increase of tyre size. It is also noted that the friction increases with decreasing the temperature below zero degree centigrade. Friction is found dependent on density and bearing capacity of snow. The results refer only to measurements at very slow speed.

Snow is the type of soil with which many vehicles have to cope in modern days. Yet the knowledge of the physical processes which take place in this material is rather limited and the studies of the problems have resulted in establishing the foundations of what is called snow mechanics[1]. Most of the work has been carried out in connection with the snow compaction. The present interest in snow mechanics is connected with the oversnow movement of vehicle.

Some work has been carried out for determining the physical and mechanical properties of ice by Nye[2] and Glen[3]. The frictional properties of ice near 0°C have been determined by Bowden & Hughes[4]. The results show that near 0°C the sliding behaviour is determined by the formation of thin film of water produced by heating. At lower temperatures the friction of ice, as of other solids, is primarily due to strong adhesion at the interface and to the shearing of the junctions so formed (Bowden & Tabour 1954)[5]. The work in connection with the icing of aircraft and ships sailing in polar seas, has been reported by Loughbourough & Haas.[6] The friction on ice of some small inflated rubber tyres sizes 8 in. and 6 in. diameter was measured by Niven[7] under controlled conditions in connection with the landing of aircraft on the frozen lakes. The coefficient of friction was found as low as 0·01 or even lower for a hard pumped tyre when the temperature was near 0°C. During the War (1943) an intensive programme with reference to the mobility of snow vehicles was carried out under the directions of Dr. Kamm[8] in Germany. During these tests horizontal loads at the movement of failure were measured. The German apparatus was not fitted with simultaneous loading equipment. It enabled one to determine experimentally the tractive effort for various vertical loads V and for various types of plates using separate loading. Later on Bekker [9, 10] modified the same apparatus in such a way that it was fitted with simultaneous loading equipment and got very good results. A project on snow crossing chains was taken up in 1962 in Defence Laboratory, Jodhpur to develop suitable attachment to the tyres of a jeep for crossing over the snow. The chains were designed and fabricated locally and were tried over snow during February—April 1963. The chains showed very satisfactory results but it was realised that these chains may not be very useful for the fresh snow. It was, therefore, considered that "studies of the physical properties of snow" may be carried out throughout the season so that these may be correlated with the vehicle mobilities on snow and therefore the following properties for changing conditions of snow were investigated in the year 1963—64.

(*a*) The friction of pneumatic rubber tyres on snow surfaces

(*b*) Density of snow

(*c*) Bearing capacity of snow

In the present report only (*a*) and (*b*) have been mentioned. The results on bearing capacity of snow would be reported elsewhere.

EXPERIMENTAL

Rolling Resistance

An apparatus as shown in Fig. 1 for the determination of rolling resistance of pneumatic rubber tyres on snow was designed and fabricated at the workshop of Defence Laboratory, Jodhpur and was installed at Field Laboratory, Gulmarg. A tray (5′ long, 14″ wide and 8″ deep) was fitted with snow taken from outside with the help of a spade. This tray rested on several ball bearings so that it may move forward and backward. With this arrangement, observations were possible on different speeds though results are not reported here. Whenever the snow fall was there, the tray was placed outside to collect fresh undisturbed snow and observations were taken when it was filled completely. The wheel was fitted with a lowering arrangement in such a way that the whole load was borne by the wheel resting on snow in the tray. This frame was pulled horizontally with a rope passing over a pulley fitted with ball bearings. The horizontal force which moved the wheel forward was taken as the rolling resistance at the particular load, inflation pressure and temperature. The results must be considered approximate. Getting exact pepetition in friction measurements is a constant source of disappointment to the experimenta list and when conditions are such that the wheel starts the stick-slip motion, it becomes almost guess work to assign the correct value of rolling resistance. Poor repetition at low temperatures was therefore expected. Observations were made with varying tyre size (5·90–15 and 16×4) whose diameters were 25″ and 16″ respectively. The inflation pressure was varied from 5 psi to 40 psi though the results are shown only from 10 psi to 35 psi. Particular attention was paid to the tyre 5·90–15 which is in common use now-a days. The rolling resistance represents the conditions of a driven wheel and not the driving wheel.

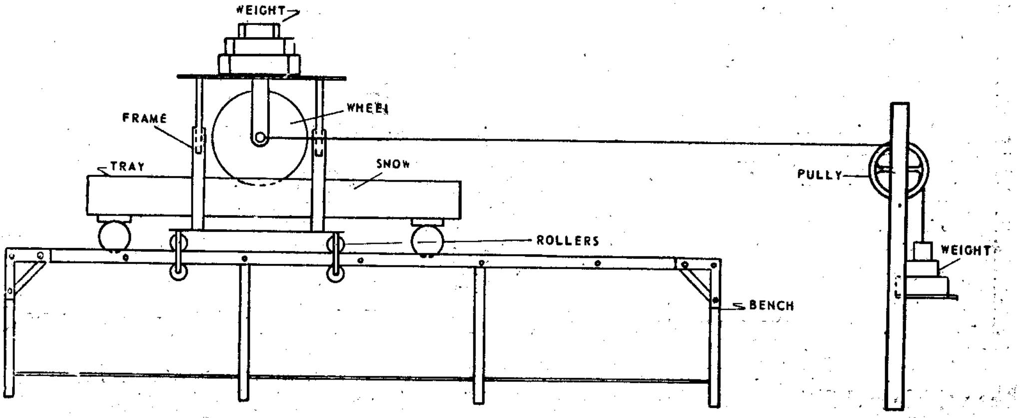

Fig. 1—Diagramatic sketch for determination of rolling resistance of pneumatic rubber tyres on snow.

Density

Four aluminium cubical containers measuring inside 10 cms × 10 cms × 10 cms open at the top were constructed. The container was weighed empty and was kept outside during snow fall and when filled, was weighed again. The density of snow *gms/c.c.* was thus calculated. On other days when it was not snowing, the container was filled with snow removed from outside (surface). The results are shown in Table 1.

RESULTS AND DISCUSSION

The rolling resistance for the wheel 5·90–15 and 16×4 are shown in Figs. 2 and 3 at different loads for different inflation pressures, as shown in the curves, at 0°C. It is seen that the rolling resistance is directly proportional to the applied load. Experiments have also shown that when the load is increased, the area of the true contact and thus that of water film have to increase in order to adjust the higher pressure and that the friction coefficient is independent of load and area within a certain range. It is also seen that it decreases as the inflation pressure increases. It is well known that the value of the sliding friction is greater than the rolling friction. At low inflation pressures the tyre is deflected with load and the surface of the tyre in contact flattens, thereby increases the area of contact. In this condition, the sliding friction plays an important part and therefore the higher values of rolling friction at low inflation pressures under the similar conditions are attributed. This is appreciable at very low inflation pressures, *e.g.* from 5 psi to 15 psi. From 20 psi to 30 psi, no appreciable difference in rolling resistance under the same conditions, is observed. The coefficient of friction for both the wheels is calculated from the observations plotted in Figs. 2 and 3 and it is found that the value of the coefficient of rolling friction is greater for the smaller wheel.

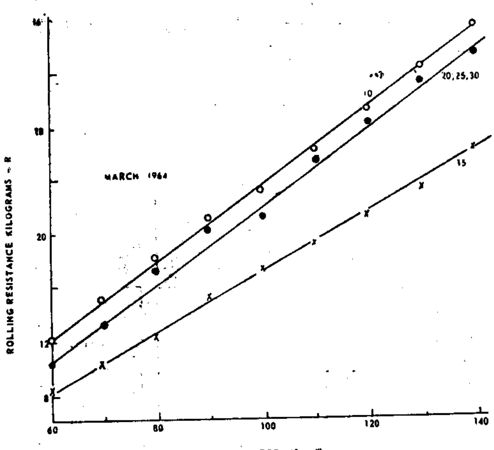

Fig. 2—Graphs showing rolling resistance at various inflation pressures atc° plotted against load for wheel 5·90—15 at variant conditions of snow.

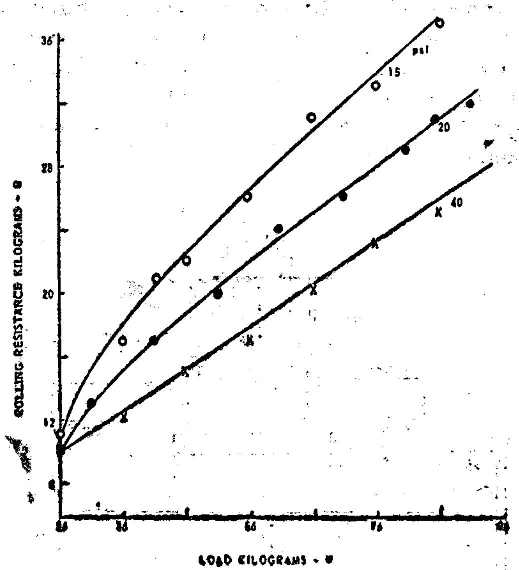

Fig. 3—Graphs showing rolling resistance at various inflation pressures at—1°C plotted against load for wheel 16 × 4 for fresh snow.

In low temperatures, when the heat of friction produces insufficient film, the friction increases and, as Bowden[4] pointed out, reaches values at low temperatures having the same order of magnitude as those of other rubbing solids.

It is seen in Figs 4 and 5 that the rolling resistance increases as the temperature decreases. The explanation is simple if one accepts the modern theory that the surface of a solid is covered with asperities and that friction is due to adhesion of these asperities. In this instance, the snow is to be regarded as covered with asperities composed of water molecules held together by strong molecular forces, so long as the temperature is below 0°C. As-soon as the temperature arises above 0°C, these forces disppear and rubber is then adhering to something which has ceased to be a solid, one could accordingly expect the friction to drop. The above results are in accordance with this view.

In Figs, 6 and 7 the rolling resistance is plotted against the applied load for varying conditions of snow such as temperatures and density. It is interesting to note that it is dependent on the density. The density of fresh snow was found to be 0·103 gm/cc while of hard snow, as found to be 0·435 gm/cc . The density of snow increases as the temperature decreases but maximum density was found in the month of March when the temperature was 0°C. In the month of March, the ambient temperature rises and snow starts to melt and becomes hard, thereby increasing the density and also the bearing capacity. It would be seen from these graphs that the friction is appreciable for the fresh snow and points deviate from the straight line but in the case of hard snow all the points fall on the same straight line and friction is low.

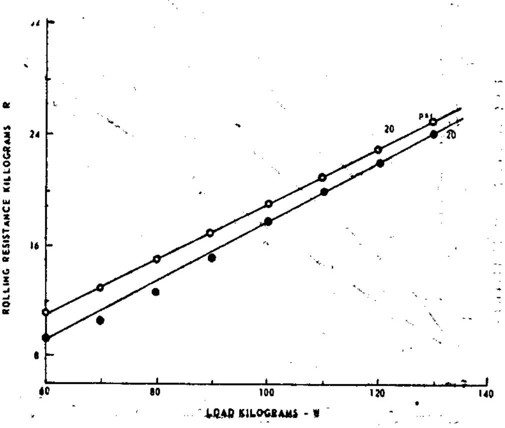

Fig. 4—Graphs showing rolling resistance at various temperatures plotted against load at 20 psi for wheel 5·90—15 for variant conditions of snow.

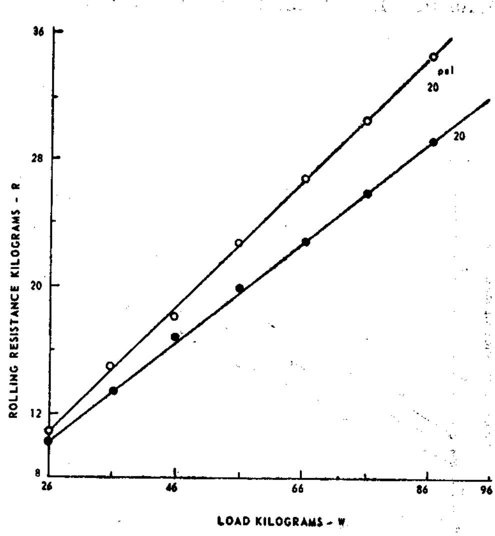

Fig. 5—Graphs showing rolling resistance at various temperature plotted against load at 20 psi for wheel 16 × 4 for variant condtions of snow.

TABLE 1

FRICTION COEFFICIENTS TYRE SIZE 5·90—15,

T°C	psi 10	15	20	25	30	35	Density gm/cc	Snow conditions
0·0	0·20	0·19	0·17	..	..	0·17	0·423	Hard
0·0	0·22	..	0·18	0·22	0·22	..	0·131	Fresh
—1·5	..	0·17	..	..	..	..	0·155	Fresh
—9·0	..	..	0·19	..	0·23	..	0·295	Aged for 4 days
—10·0	..	..	0·20	0·23	..	0·20	0·132	Fresh

The mechanism of snow friction is not very clearly understood and there is no definite theory which would attempt to solve the problem quantitatively. Haefeli[1] suggeted that snow is slippery by its very nature due to the fact that it is of a homogeneous substance, but a three phase system in which solid, liquid and gaseous (vapour) states coexist at a thermodynamic equilibrium corresponding to a given pressure and temperature. Any change of pressure or temperature causes an immediate shift in the phase composition, thus involving fluctuations in the structure of the matter. Since snow is an aggregate of ice crystals and air, the factors involving the phase change are particularly active. An increase in pressure and temperature between a rolling body and snow will invariably increase the amount of liquid phase, thereby providing the rubbing surfaces with lubricant which considerably reduces the friction coefficient.

Table 1 gives some further details on the values of friction coefficients also taken from the graphs. Some of these values have been read to the second significant figure but variations in snow conditions do not really warrant this accuracy. The object of tabulating

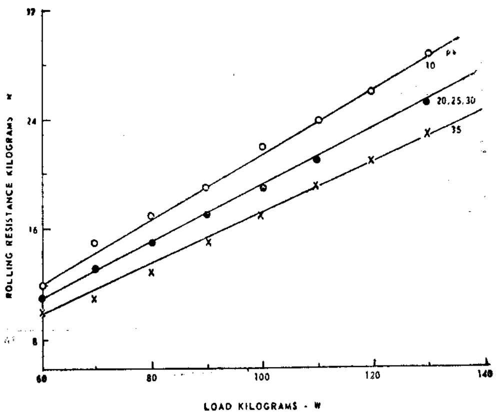

Fig. 6— Graph showing rolling resistance at various inflation pressures plotted against load for wheel 5·90—15 at variant conditions of snow.

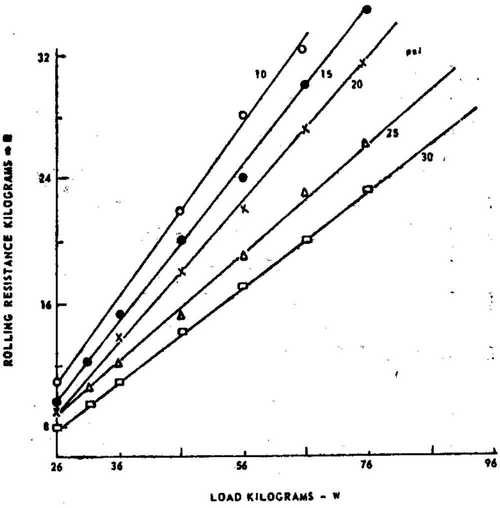

Fig. 7— Graphs showing rolling resistance at various inflation pressures plotted against load for wheel 16 × 4 at variant conditions of snow.

them is to demonstrate the wide variety of friction coefficients, each of which is a perfectly good value for a particular tyre at a particular temperature on a particular snow surface The important conclusion to draw from Table 1 is that 0·22 is a safe coefficient to take for the rolling friction of the pneumatic rubber tyres for the size or 5·90—15 on the snow surface. If the worst conditions are to be considered then it is suggeted that the full scale tests, with variable parameters such as the size of the tyre, the load, the apparent contact area, the temperature and the bearing capacity of snow, should be made. It is also recommended that the size of the tray should be increased from 5′ long 14″ wide and 8″ deep to 5′ long 2′ wide and 2′ deep and observations should be made at different speeds so that the results represent the actual field conditions. The results are required for calculating the power required for a vehicle which is supposed to ply over the snow surfaces.

CONCLUSIONS

1. The frictional force is proportional to load.
2. The frictional force decreases with inflation pressure of the tyre.
3. The frictional force increases as the temperature decreases below zero degree centrigrade.
4. The frictional force decreases as the size of the tyre increases.
5. The frictional force decreases as the density and bearing capacity of the snow increase.

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