



Dependence Of Static Frictional Force On Surface Area In Contact Separate From Its Dependence On Load.

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Abstract:

Friction occurring between the surfaces of two objects in contact, under the action of force parallel to surfaces in contact is known as static friction. Kinetic friction occurs between objects in contact, one moving with respect to the other. Several experiments have been conducted and theories have been put forth in order to explain the phenomenon of friction. Most famous laws of friction tell us that the frictional force only depends on mass of the object and nature of surface but not on the surface area in contact. There are some theories which give the dependence of surface area in contact on the load for cylindrical surfaces. Thus this dependence of frictional force on surface area is linked to and leads to dependence on mass. In the present work dependence of static frictional force on the surface area of the object in contact is investigated, separate from its dependence on mass. Experiments are performed on five series of wooden blocks comprising of total 35 blocks and two series of Perspex blocks comprising of 12 blocks. The results show that static frictional force is directly proportional to load. In addition results show that static frictional force is linearly dependent on surface area in contact. This dependence on surface area in contact is not linked to dependence on mass but is separate from dependence on mass. Accordingly, modified laws of friction are proposed.

1. INTRODUCTION

Frictional forces are very important in our daily lives. Frictional forces allow us to walk or run and are necessary for wheeled vehicles. Frictional forces exist between solid surfaces stationary or moving relative to each other.

In 15th century, Leonardo Da Vinci was the first who formulated the laws of friction (200 years before Newton even defined what force is). He arrived at the conclusion that can be summarized in today's language as two fundamental Laws of Friction. First, the frictional force is proportional to the normal force, or load. Second, the frictional force is independent of the contact surface area. Also he introduced the term coefficient of friction and experimentally determined its typical value of 0.25. After Leonardo Da Vinci, French physicist Guillaume Amontons rediscovered the same results (1699). The proportionality of the frictional force to the normal force is, therefore, known as "Amontons' Law". For several centuries after Amontons' work, scientists believed that friction was due to the roughness on the surfaces [1].

Leonard Euler was the first to lay the foundation of the mathematical way of dealing with the laws of friction. He also introduced the differentiation between static frictional forces and kinetic frictional forces. He assumed that friction originates from the interlocking between small triangular irregularities and that the frictional coefficient is equal to the gradient of these irregularities [1].

When two plane surfaces are placed together the actual area in contact must be very much less than the surface area due to irregularities on the surfaces. Even if the surfaces are very much carefully polished and made flat as possible, some valleys and hills always remain present on the surface [2].

It is assumed by some researchers that the real area of contact between two metallic surfaces is determined by considering plastic and elastic deformation of their asperities and under this assumptions come to the conclusion that area of contact A is proportional to some power of the load W for cylindrical surfaces i.e. $A = k W^n$ [1, 2]. Hertz considered plane surface with irregularities and found that if deformation is truly elastic, the area of contact is related to the load W by $A = KW^{2/3}$. Here, K is a constant depending upon the local radius of curvature of surface irregularities and the elastic constants of the materials [3].

Archard has developed a model in which he considered the contact of two nominally flat surfaces [3]. Out of the two surfaces, one surface was supposed to be perfectly flat and the other covered with spherical identical protuberances. When the load is increased, existing contact areas increase in size and new contact areas are created. Theoretical analysis of the model for this arrangement shows the value of power of W i.e. n was $4/5$ [3]. Also Archard observed that under different circumstances which he has assumed in his model, value of n varies. When he assumed the surfaces under load, values of n were found to be $2/3$ for perfectly smooth spheres and become $8/9$ when one set of protuberances is superposed. Whereas when protuberances of two sizes are present, n is $26/27$, values of n were found to be $4/5$, $14/15$ and $44/45$ by considering division of spherical identical protuberances into smaller and smaller spherical identical protuberances. Value of n varies with different model [4,5].

Bowden and Tabour found that the results obtained for the flat surfaces are not very different from the results obtained for the curved surfaces [2]. Bowden and Tabour have also found that the dependence of contact surface area on load has connection with the deformation mechanism and found different results when they considered plastic deformation than when they considered elastic deformation [2]. They found that theoretical results show better agreement with the experimentally obtained results when they considered plastic deformation than elastic deformation. In addition to this they found the dependence of contact surface area on load varies for larger loads from that for smaller loads and they have tried to explain this variation by considering elastic deformation for smaller loads and plastic deformation for larger loads. However even then the agreement between theory and experimental results was not very good.

Greenwood⁶ found that the origin of the laws of friction, and particularly of the proportionality between contact surface area and load, lies not in the ideal plastic flow of individual contact spots but simply in the statistics of surface roughness.

Overall we can say that the dependence of contact surface area on load is not yet clear and varies with the model and deformation mechanism considered. Further, no attempt has been made for the experimental verification of most of the the above models.

As pioneering work in this subject we must mention the works of Archard [1], who concluded that the contact area between rough elastic surfaces is approximately proportional to the normal force. Further important contributions were made by Greenwood and Williamson, Bush, and Persson [5, 7, 8]. The main result of these examinations is that the real contact areas of rough surfaces are approximately proportional to the normal force.

In many research papers related to the frictional force between two surfaces it is found that they have mainly focused on the actual surface area in contact and its dependence on load. Also it is found that this dependence varies with different model which hardly shows any agreement with experimental results [2]. Again, this relationship i.e. dependence of surface area in contact to the load is not sufficient to explain the nature of frictional forces because it does not make clear the dependence of frictional force on surface area of the object since the dependence of surface area in contact on the load is not well understood and varies with the model considered.

From the above historical review of friction and progress in last few decades it is clear that there is not much development in this direction and hence laws of friction given by Leonardo Da Vinci in 15th century remain unchanged.

From the literature, as discussed above, it is found that the actual surface area in contact depends only on the load. It means that if we consider two blocks with same mass but different surface areas placed on a horizontal plane of the same material, the frictional force must be the same since actual area in contact depends only on load and not on the surface areas of the blocks. Also from literature we find that many scientists believe friction to be due to irregularities on the surface. Combining these two, it means smaller and larger surfaces both have same number of irregularities in order to keep actual area in contact constant.

However, since the surface area under consideration is of the same material, the number of irregularities can not be same for both surfaces, small and large. Hence we can say that the models showing relation between the actual surface areas of contact to the load need revision.

In general, it is agreed upon that when an object resting over another surface is moved by applying a force, then the static frictional force is given by,

$$F_s = \mu F_N \quad (1)$$

Where F_s is static frictional force, μ is coefficient of static friction and F_N is normal force.

In the present work we have studied separately the dependence of static frictional force on load applied and the surface area in contact and come out with single empirical relation which includes both factors. In this work we have experimentally determined dependence of frictional force on load and on surface area in contact for wooden surfaces and for Perspex surfaces. Also we have obtained an empirical relation for the same.

2. BASIC IDEA BEHIND THE PRESENT WORK

Friction is purely a surface phenomenon and most of the scientists believed that friction is due to the roughness (or irregularities) on the surfaces. It means that more the irregularities on the surfaces more is the frictional force. It implies that if we increase the surface area keeping the mass of the body constant, frictional forces must have to increase. But according to the second statement of the laws of friction, frictional force is independent of contact surface area. This is in contradiction to the assumptions made by most of the scientists to explain frictional forces. As friction is purely a surface phenomenon, it must have dependence on the surface area in contact, in addition to dependence on load, which is investigated in the present work.

3. EXPERIMENTAL WORK

The experiments are conducted as follows:

A block is taken and is placed over a horizontal plane made of the same material. The block is connected to a cord that wraps over a frictionless pulley. The other end of the cord has a load 'L' attached to it as shown in the Fig.1. In the first case blocks of wood are placed on wooden plane. Same experimental arrangement is used in case of Perspex where the block of Perspex is placed over the horizontal plane made up of same material.

Initially, a small force is exerted on the block, attempting to pull it on one side, by applying a small load. It is found that it remains at rest on the horizontal plane. Then applied force is gradually increased by increasing the load in small steps. The value of load at which the block just starts to move is noted. The value of load at which the block just starts to move is nothing but the static frictional force. In this way the values of static frictional force for all the samples of the series A, B, C, P, Q, M and N are obtained.

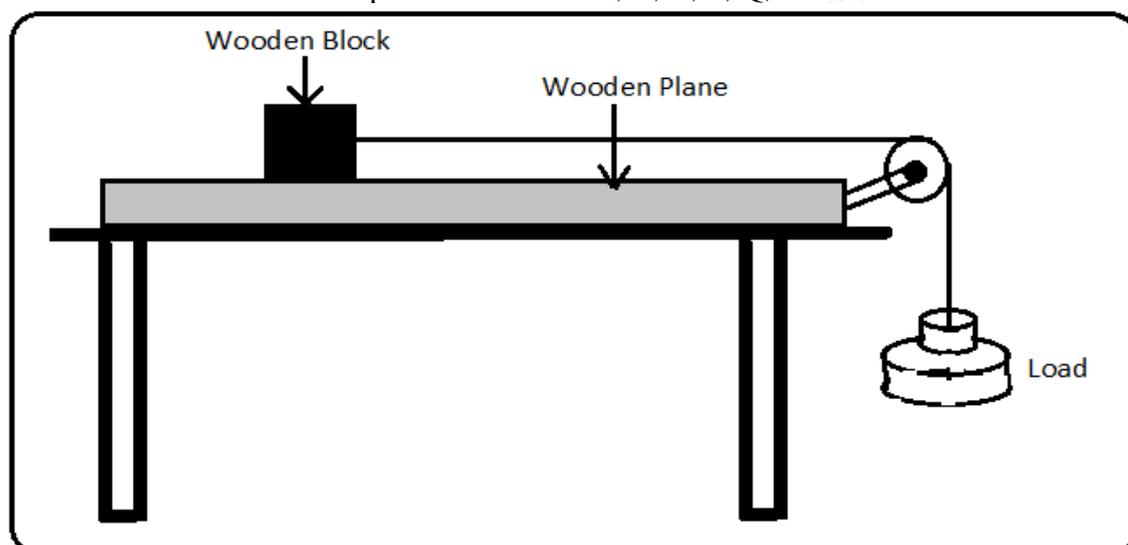


Fig. 1. EXPERIMENTAL SET UP

3.1. Preparation of samples

For the experiment, we have prepared five series of the samples of wooden blocks and two series of blocks of Perspex. Series A, series B, series C, series P and series Q are the series of wooden blocks. Each series contain seven samples of wooden blocks. In all 35 blocks of wood are used. Series M and N are the series of blocks of Perspex. Each series contain 6 samples of blocks of Perspex. The sample series are as follows.

3.1.1. Series of samples of blocks having same surface area but different mass.

Out of these five series of wooden blocks, series A, B and C are the series of wooden blocks having same surface area of one of the faces, but different mass. Again, all the samples of these three series are prepared from same large piece of wood. First, a single large piece of wood is taken. Then one of its faces is processed so that the surface roughness of that face remained constant. Then this piece of wood is cut into small blocks of required dimensions. In this way we have prepared series A, B and C of wooden blocks. It means series A, B and C are differing only slightly in surface roughnesses of the samples and all the samples of same series possess same surface roughness.

Series M is series of blocks of Perspex having same surface area of one of the faces but different mass. All the samples of this series are prepared from same large piece of Perspex so that the surface roughness of one of its faces remains constant. Then this large piece of Perspex cut into small blocks of required dimensions. In this way we have prepared all the samples of the series M.

Schematic diagram of the samples of these series are as shown in Fig. 2.

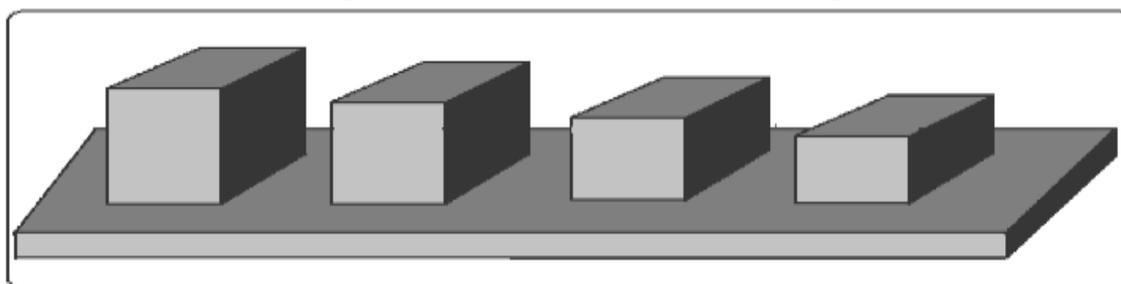


Fig. 2. DIAGRAM SHOWING SET OF WOODEN BLOCKS HAVING SAME SURFACE AREA BUT DIFFERENT MASS.

3.1.2. Series of the samples of blocks having different surface area but same mass.

Series P and series Q are the series of the samples of wooden blocks having different surface area, but same mass. Again, all the samples of these three series are prepared from same large piece of wood. First, a single large piece of wood is taken. Then one of its faces is processed so that the surface roughness of that face remains constant. Then this piece of wood is cut into small blocks in required dimensions. In this way we have prepared series P and Q of wooden blocks. Series P and Q also differ only slightly in their surface roughness. Blocks in the same series have same surface roughness.

Series N is the series of blocks of Perspex having different surface area but same mass. All the samples of this series are prepared from same large piece of Perspex so that surface roughness of one of the faces remains constant. Then this piece of Perspex was cut into small blocks in required dimensions. In this way we have prepared series N.

Schematic diagram of the samples of these series is given in Fig. 3.

Results for series of samples of blocks having same surface area but different mass are presented below.

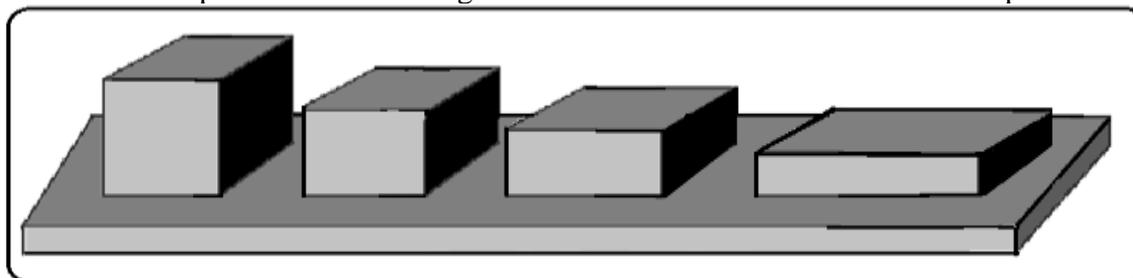


Fig. 3. DIAGRAM SHOWING SET OF WOODEN BLOCKS HAVING DIFFERENT SURFACE AREA BUT SAME MASS.

4. RESULTS

4.1. Series of samples of blocks having same surface area but different mass.

4.1.1. Series of samples of wooden blocks having same surface area but different mass.

The results obtained for the series A, B and C have been presented in the Fig- 4. For the samples of the series A, B and C it is found that, the values of static frictional forces increase monotonically with increase in mass of the blocks. These are the series of samples having same surface area in contact with the horizontal wooden plane and are slightly differing in their surface roughness. Hence from the results obtained for the series A, B and C it is found that static frictional force for all the series shows similar trend. The frictional force is found to be linearly dependant on mass with small deviation. It is found that small variations in surface roughness do not alter the frictional force appreciably.

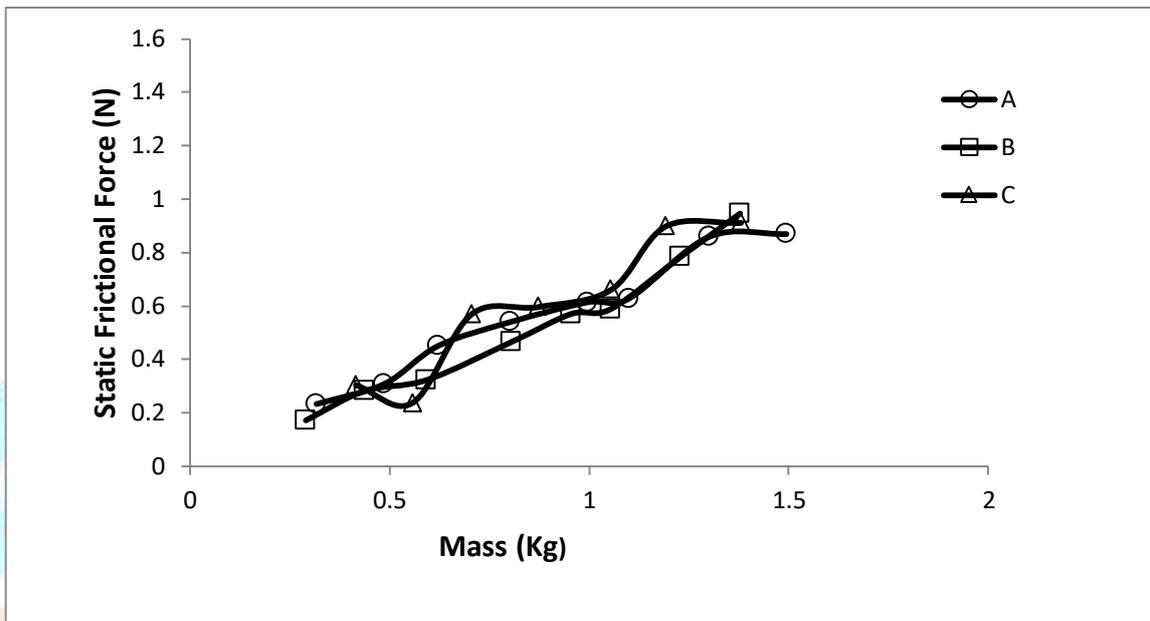


Fig. 4. COMPARISON OF EXPERIMENTAL RESULTS FOR THE SERIES OF WOODEN BLOCKS HAVING SAME SURFACE AREA BUT DIFFERENT MASS.

4.1.2. Series of samples of Perspex blocks having same surface area but different mass.

The results obtained for series M have been presented in the Fig- 5.

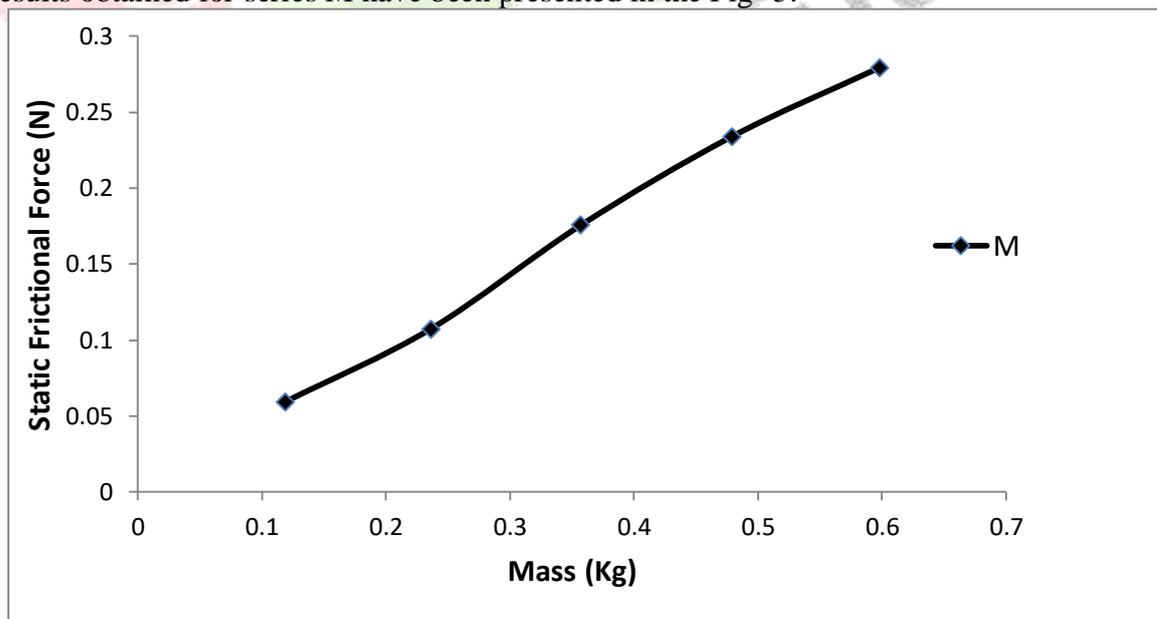


Fig. 5. COMPARISON OF EXPERIMENTAL RESULTS FOR THE SERIES OF BLOCKS OF PERSPEX HAVING SAME SURFACE AREA BUT DIFFERENT MASS.

Results obtained for the series M of block of Perspex having same surface area in contact and different mass are similar to those obtained for wooden samples. In case of Perspex also the values of static frictional force increase with increase in mass of the blocks.

4.2. Series of the samples of blocks having different surface area but same mass.

Results for the series of the samples of blocks having different surface area but same mass are given below.

4.2.1. Series of the samples of wooden blocks having different surface area but same mass.

Series P and Q are the series of wooden blocks having same mass but different surface area in contact with the horizontal wooden plane. The dependence of static frictional force on surface area in contact for wooden blocks is shown in the Fig. 6. For the samples of the series P and Q interesting results have been obtained. The result shows that static frictional force increases as surface area of the block increases keeping mass of block constant.

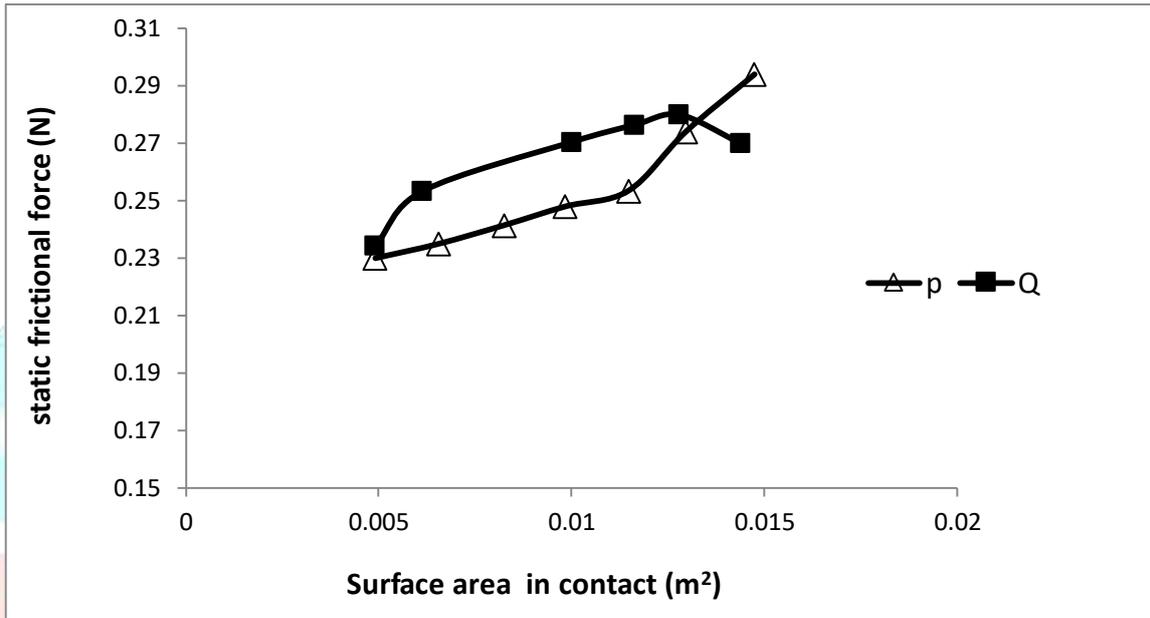


Fig. 6. COMPARISON OF EXPERIMENTAL RESULTS FOR THE SERIES OF WOODEN BLOCKS HAVING DIFFERENT SURFACE AREA BUT SAME MASS.

4.2.2. Series of the samples of Perspex blocks having different surface area but same mass.

The results obtained for series N which is the series of blocks of Perspex having same mass but different surface area of the block of Perspex have been presented in the Fig. 7. From the results obtained for series N it is found that the static frictional force increases as surface area of the block of Perspex increases.

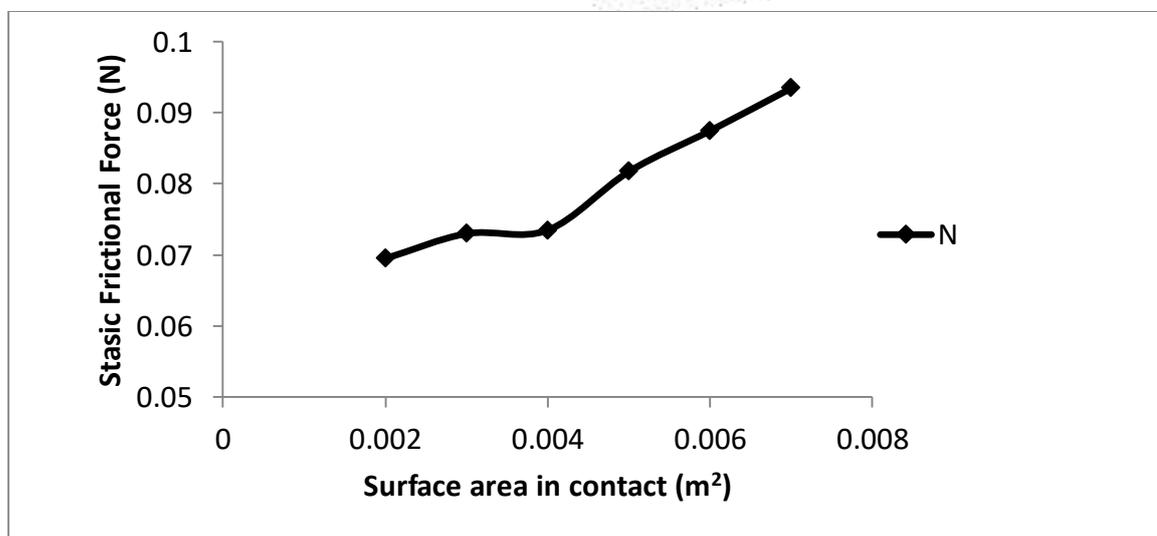


Fig. 7. COMPARISON OF EXPERIMENTAL RESULTS FOR THE SERIES OF BLOCKS OF PERSPEX HAVING DIFFERENT SURFACE AREA BUT SAME MASS.

Hence we have observed that frictional force depends on surface area, and this dependence is not linked to dependence on mass and is separate from dependence on mass. The results obtained for the series P, Q and N are in direct contradiction to the second statement of the laws of friction which states that the frictional force is independent of the contact surface area of the block.

Our experimental results show that frictional force depends on surface area, and this dependence is separate from its dependence on load. As frictional forces are found to depend on mass as well as on contact surface area, hence equation (1) needs modification. We have obtained new equation for frictional force which would explain the dependence of frictional force on both mass and contact surface area by using the technique of curve fitting.

5. EXPRESSION FOR FRICTIONAL FORCE

The established expression for static frictional force is given as,

$$F = \mu m g \quad (2)$$

This gives the dependence of frictional force on mass m of an object only but the obtained results for both wood and Perspex clearly shows that frictional force also shows strong dependence on surface area in contact. We have obtained a new equation for frictional force by curve fitting technique using our experimental results.

The new equation which we have obtained for frictional force is

$$F = \mu m g (a S + b) \quad (3)$$

Where ' μ ' is the coefficient of friction, ' m ' is the mass of the object, ' S ' is the surface area of the block, ' a ' and ' b ' are some constants.

Equation (3) shows that frictional force is directly proportional to the mass of the object and also increases with increase in the contact surface area.

We know that,

$$m g = -F_N \quad (4)$$

Hence equation (3) becomes,

$$F = \mu F_N (a S + b) \quad (5)$$

Comparison of the results obtained by equation (5), with the experimental results for the wooden blocks is shown in Fig. 8 and Fig. 9 and for the Perspex blocks are shown in the Fig. 10 and Fig. 11.

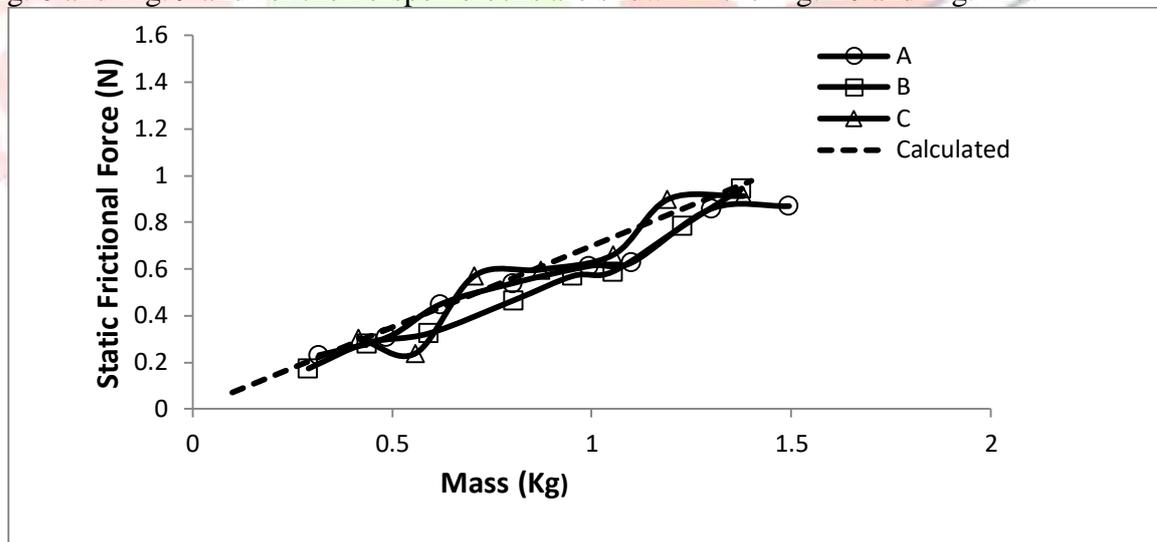


Fig. 8. COMPARISON OF EXPERIMENTAL RESULTS FOR SERIES A, B AND C WITH THEORETICALLY OBTAINED RESULTS FROM EQUATION (5).

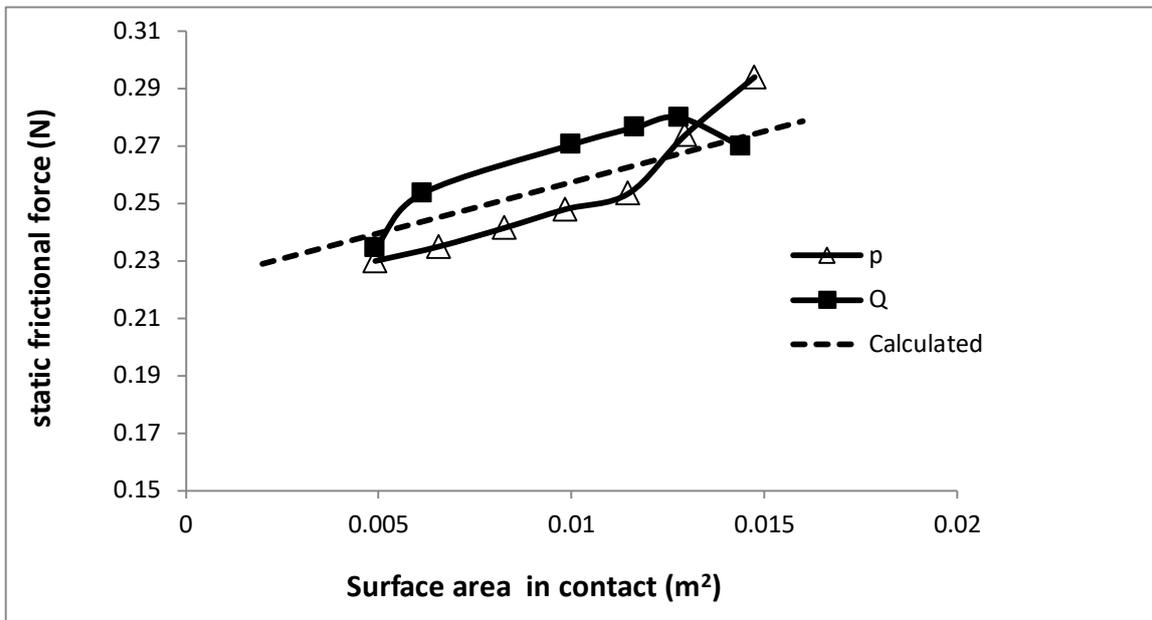


Fig. 9. COMPARISON OF EXPERIMENTAL RESULTS FOR SERIES P AND Q WITH THEORETICALLY OBTAINED RESULTS FROM EQUATION (5).

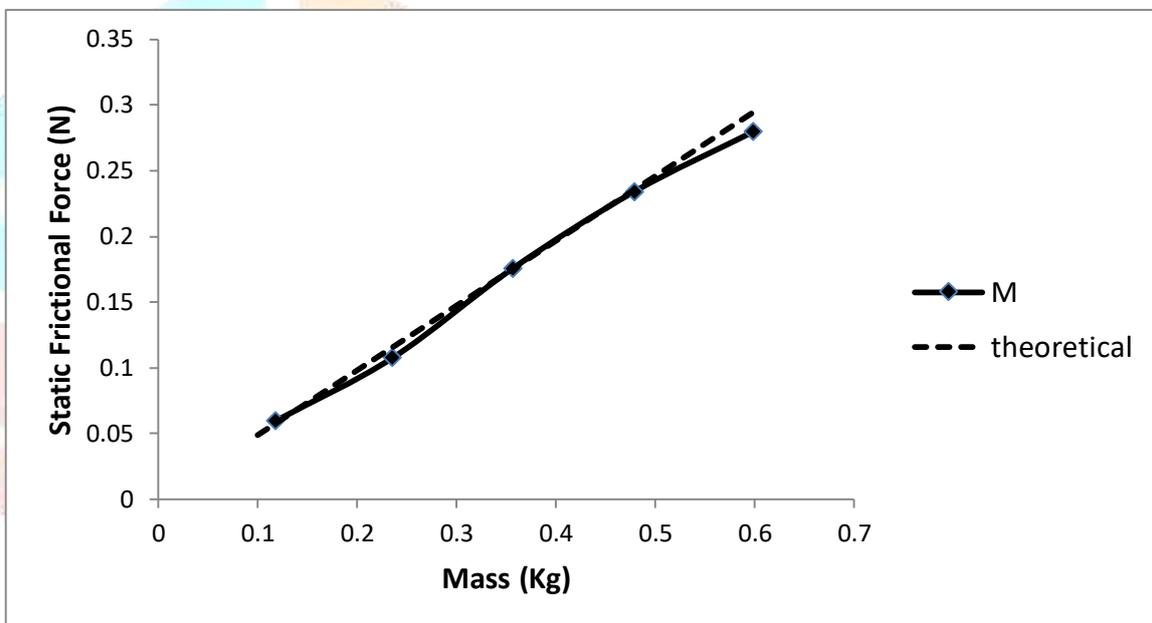


Fig. 10. COMPARISON OF EXPERIMENTAL RESULTS FOR SERIES M WITH THEORETICALLY OBTAINED RESULTS FROM EQUATION (5).

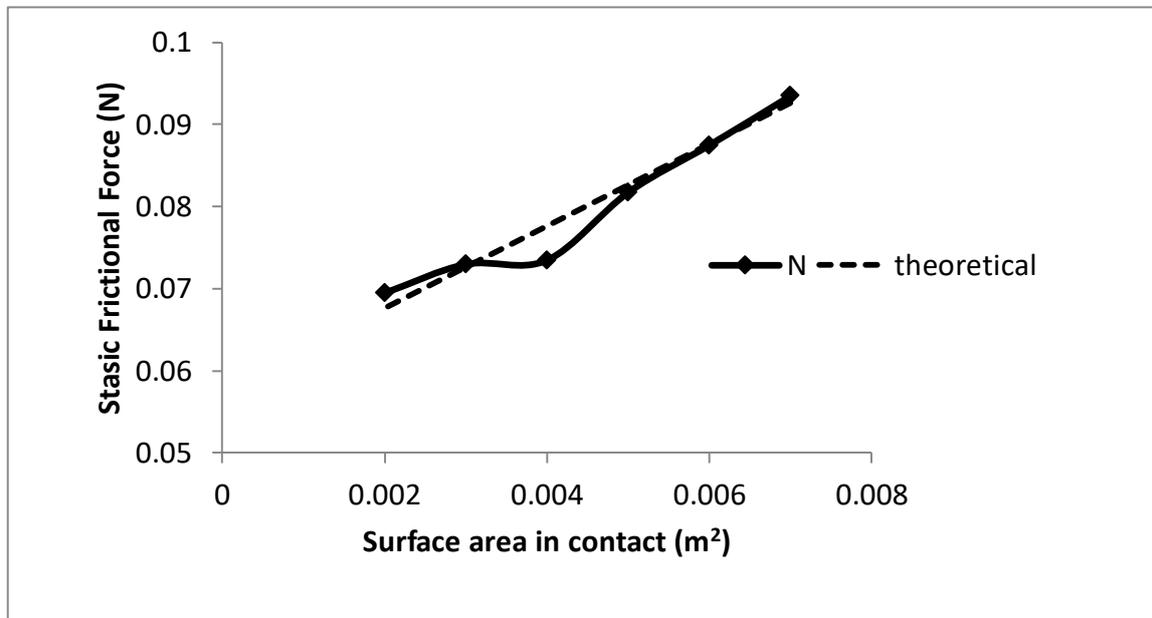


Fig. 11. COMPARISON OF EXPERIMENTAL RESULTS FOR SERIES N WITH THEORETICALLY OBTAINED RESULTS FROM EQUATION (5).

Fig. 8, Fig. 9, Fig. 10 and Fig. 11 clearly show that the results obtained from the equation (5) are in good agreement with the experimental results.

6. DISCUSSION

It is observed from curve fitting to the experimental data that a single equation giving dependence of frictional force on mass of the block and surface area explains the results of both categories of series (same mass and different surface area, same surface area and different mass) for both the materials. The dependence on surface area shows that even if the surface area is zero, there is still some frictional force (due to presence of constant 'b'). This is in agreement with the observation that if a spherical surface is pulled (without rolling) there exists some friction. μ , a and b are constants for particular material and are different for different material.

7. CONCLUSIONS

From the experimental results it is observed that frictional force depends on surface area and increases with increase in surface area. From curve fitting on the data it is seen that frictional force is linearly dependent on surface area. In addition, it is observed that the dependence on surface area is separate from dependence on mass. Thus it is observed that the laws of friction need revision. The new laws of friction are proposed as follows:

Frictional force is directly proportional to the normal force (or load).

Frictional force is linearly dependant on surface area and this dependence is separate from its dependence on mass.

μ , a and b are constants for particular material and are different for different material.

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FIGURE CAPTION

Fig. 1. EXPERIMENTAL SET UP

Fig. 2. DIAGRAM SHOWING SET OF WOODEN BLOCKS HAVING SAME SURFACE AREA BUT DIFFERENT MASS.

Fig. 3. DIAGRAM SHOWING SET OF WOODEN BLOCKS HAVING DIFFERENT SURFACE AREA BUT SAME MASS.

Fig. 4. COMPARISON OF EXPERIMENTAL RESULTS FOR THE SERIES OF WOODEN BLOCKS HAVING SAME SURFACE AREA BUT DIFFERENT MASS.

Fig. 5. COMPARISON OF EXPERIMENTAL RESULTS FOR THE SERIES OF BLOCKS OF PERSPEX HAVING SAME SURFACE AREA BUT DIFFERENT MASS.

Fig. 6. COMPARISON OF EXPERIMENTAL RESULTS FOR THE SERIES OF WOODEN BLOCKS HAVING DIFFERENT SURFACE AREA BUT SAME MASS.

Fig. 7. COMPARISON OF EXPERIMENTAL RESULTS FOR THE SERIES OF BLOCKS OF PERSPEX HAVING DIFFERENT SURFACE AREA BUT SAME MASS.

Fig. 8. COMPARISON OF EXPERIMENTAL RESULTS FOR SERIES A, B AND C WITH THEORETICALLY OBTAINED RESULTS FROM EQUATION (5).

Fig. 9. COMPARISON OF EXPERIMENTAL RESULTS FOR SERIES P AND Q WITH THEORETICALLY OBTAINED RESULTS FROM EQUATION (5)

Fig. 10. COMPARISON OF EXPERIMENTAL RESULTS FOR SERIES M WITH THEORETICALLY OBTAINED RESULTS FROM EQUATION (5).

Fig. 11. COMPARISON OF EXPERIMENTAL RESULTS FOR SERIES N WITH THEORETICALLY OBTAINED RESULTS FROM EQUATION (5).