General.—When the subject of Engineers' materials is discussed, we enter a most extensive and varied subject. The field covers all metals and their alloys, natural and manufactured, building materials, and many natural and prepared organic substances. It is essential for our daily use to have supplies of steel, copper, aluminium, and their alloys, and just as necessary to have timber, concrete, and other building materials for our industrial existence.

The demands of modern civilisation and war are so diverse, that it has become necessary and advantageous to develop many of Nature's other materials for our service. Of the many organic substances whose properties have become known and taken their place as being amongst the important material for our use, one of the most outstanding is "RUBBER."

Rubber, in many of its uses, such as shoes, weatherproof clothing, belting and water hose, has been well known for a long time. Its use by engineers first gained prominence in the design and development of the pneumatic tyre. This was one of the big factors in the development of road transport and, consequently, the automotive industry. However, it is only comparatively recently that its general value as an engineers' material has become known, and its application greatly developed. It is on these developments that this paper is written.

Raw Material.—Rubber is obtained by coagulating the latex or milky substance which occurs beneath the bark of the "Hevea" tree, of South America. This latex is taken from the tree by systematic tapping without injuring the tree.

The "Hevea" tree has been most successfully developed in plantations in Ceylon, Malay, Java, New Guinea, and Equatorial Africa to such an extent that the bulk of the world's supply now comes from the East Indies and surrounding countries.

Rubber in its natural state has little direct application as it is very plastic, and is affected greatly by changes in temperature.

Vulcanisation.—Rubber first became a material of importance after the discovery of "vulcanisation." This is a process by which the addition of suitable quantities of sulphur to the rubber at the right temperature causes a combined mechanical and chemical change in the rubber structure, resulting in a material
which is no longer plastic, but elastic and unaffected by normal temperature changes. Otherwise, it becomes a stable substance with definite mechanical properties which can be determined and repeated.

Compounded Rubber.—Vulcanised, pure rubber has an ultimate tensile strength of approximately two thousand pounds per square inch, and an elongation of from seven hundred to nine hundred per cent. While rubber in this state has many applications, it is as a result of the introduction of many and varied chemicals prior to vulcanising that its great range of properties or application value has so greatly developed.

Rubber is vulcanised by the controlled application of heat, but by suitable compounding rubber steam hose is manufactured. Rubbers can be made abrasive resisting as in a tyre tread. It is also a suitable bonding material for certain abrasive wheels and belts. Petroleum liquids are solvents for pure rubber, yet a suitably compounded, synthetic rubber is used in hose for conveying petrol.

Rubber has valuable properties in tension, shear and compression, and these properties vary with the nature of the compounding, but are definite for any particular compounding. Rubber can be compounded to produce a rubber product from the softness of pure rubber to the hardness of ebonite.

Rubber can be bonded to fabric, wood and metals, and moulded to almost any shape. It can be made acid resisting, have high electrical insulation value, or made a conductor of static electricity.

These illustrations of the tremendous range of properties which can be developed by the suitable combination of chemicals with rubber, show why rubber has developed into an important material which must be considered when designing machinery or plant to obtain the most suitable and economical equipment.

Mechanical Properties.—A summary of the more outstanding mechanical properties of rubber will give a better understanding of the applications of rubber which will follow at a later stage. Colin McBeth has stated that "The greatest value of rubber is its ability to change shape under load, to resist this changing of shape, and subsequently to recover from the change imposed upon it without permanent set."

Rubber in Tension.—Depending upon the nature of the compounding of rubber, the tensile strength may vary from 500 to 5000 pounds per square inch, and the elongation will vary from
200 to 700 per cent. After a certain percentage of stretch, depending upon the type of compounding, the rubber increases in hardness. It is at this point that the rubber is most prone to oxidation, so that rubber which is to be used continuously in tension should only be stressed below this point. For the usual range of work a safe figure for tensile loading is between 30 and 70 pounds per square inch. For stocks with a high rubber content, the load deflection curve is nearly a straight line for the usual working limits. This means that the modulus of elasticity is nearly constant within this range.

*Rubber in Compression.*—Rubber, to the same extent as water, is incompressible. When not restricted it is deformable, but maintains a constant volume.

Rubber, in compression, should be limited to a normal loading of 40 to 70 pounds per square inch, or a deflection of 20 per cent, when not restricted, to prevent distortion and permanent set under continued loading.

*Rubber in Shear.*—Rubber is now widely used for machinery mounting for heavy loadings, and it has been found more practicable to make shear mountings instead of direct compression mountings. Rubber loads in shear should be kept within 40 to 70 pounds per square inch. The shear modulus of rubber varies with the hardness.

The shear calculation of typical shear supports are shown on the accompanying block:
1 FLAT SPRING IN SHEAR

\[ d = \frac{W + T}{A \times G} \]

- **d**: Deflection in inches
- **T**: Thickness of One (1) Sandwich in inches
- **W**: Load applied in vertical shear
- **A**: Area of two flat plates in square inches
- **G**: Modulus of elasticity in shear lbs. per sq. in.

2. CIRCULAR SPRINGS

\[ d = \frac{W}{2 \pi G \left( \frac{r_2 - r_1}{h_2} \right)} \left( \log e h r_2 - \log e h r_1 \right) \]

- **d**: Deflection in inches
- **W**: Load in pounds
- **h_1**: Height of bonded area inside tube in inches
- **h_2**: Height of bonded area outside tube in inches
- **r_1**: Radius of bonded area inside tube in inches
- **r_2**: Radius of bonded area outside tube in inches
- **G**: Shear modulus lbs. per sq. in.

3. TORSION SPRING

\[ \theta = \frac{W b}{4 \pi G b_0} \left( t_2 - \frac{1}{t_2} \right) \]

- **\theta**: Deflection in radians
- **Wb**: Torque
- **b**: Effective length of rubber
- **t_1**: Radius of inside bonded area in inches
- **t_2**: Radius of outside bonded area in inches
- **G**: Modulus of torsion lbs. per sq. in.

POLYGON SHAPED RUBBER BEARING
Hardness of Rubber.—The hardness of rubber varies greatly with the nature of the compounding. Hardness is measured with a “Shore” Durometer, which is a measurement of the depression of a standardised pin under a given load on the rubber under test. The tensile and compressive strengths of rubber, and the coefficients of elasticity are all dependent on the hardness of the rubber.

Applications of Rubber.—The preceding section has given very briefly some of the most important features of the properties and strengths of compounded rubber, and form the basis of its many and varied applications.

The uses of rubber cover practically all industries and most phases of civil and industrial life, and this section of the Paper will group these uses in their more important applications from the engineer’s viewpoint. Some typical applications will be described in a little detail.

Power Transmission.—One of the earlier mechanical developments of the application of rubber is its use with cotton ducks for the making of belting.

Power transmission belting is divided into two main classes.

The first group covers the different types of flat belts for ordinary pulley drives. The advantages of rubberised fabric belting are:

- Great flexibility.
- Long life.
- Can be made economically in long lengths.
- High coefficient of friction.
- Small effect of damp conditions.

The second group is the Vee Belt.

This type of belt is best used in high speed drives. It is a silent, flexible drive, can be used with small pulleys at short centres, and being used singly or in multiples, the pulley sizes are a minimum for the power transmitted.

This class of belt can be used with a Vee driving pulley and a flat driven pulley, so that it is easily adapted to existing plant where unit drives are required.

It is extensively used for the first motion drive from motors and for such applications as fan belts on motor vehicle engines.

An important part of power transmission design is the application of flexible and semi-universal joints between moving shafts where it is impossible to maintain rigid alignment. Rubber and fabric discs and couplings are widely used in this field;
apart from their long life and flexibility, their great advantage is that such flexible couplings do not require lubrication.

**Conveying of Materials.**—Rubber conveyor and elevating belts are now so generally used that they are accepted as necessary. The design of these belts are so varied that they can be used for conveying component parts for assembly in factories, for the transfer of coal from the mine pit head or from bunkers to ships, for the bulk handling of wheat, for the disposal of slag in steel works, or for the conveying of food products during their various stages of manufacture.

The tremendous use of conveyor belts has come about because they are self-containing, can be made in almost unlimited lengths at very serviceable widths, and the completed plant contains such few working parts in comparison with other methods of conveying, thus reducing to a minimum maintenance costs. Initial costs are also economical.

In conveying liquids and gases, pipelines are necessary. In many places, a flexible line is necessary, such as at ship sides, tank cars, and certain classes of machinery, suction dredges, etc. Here, rubber hose has found many applications under very varied conditions and pressure loadings.

Some of these varied applications are as follow:
- Petrol hose for use between tank ships and bulk tanks; for filling tank cars and for petrol pumps.
- Steam hose.
- Hydraulic hose.
- Oil hose for use on hydraulic brake systems.
- Water sluicing hose.
- Dredge suction hose.
- Beer and wine hoses for breweries and distilleries.

**Abrasive Protection.**—Among the more recent important developments of the application of rubber can be placed its use as an abrasive resisting material.

Ash and clinker chutes in power stations and steel plants have presented a serious problem for very many years as regards maintenance. All types of alloy steels have been developed to increase their life, but the most successful method found for greatly increasing their life is to rubber line these chutes. Four or five times the life of steel can be anticipated. For hot clinker chutes synthetic rubber is used.

Anti-abrasive linings can be rigidly attached to metal and wood parts. When damage has been caused local repairs can be made.
The rubber chemists have so developed the compounding of rubber that abrasive resisting stocks can be vulcanised not only in steam enclosed vessels but with hot air, hot water, and by exposure to ordinary atmospheric heat. This has made it possible to rubber-cover plant of varied types, and its use in the mining and metallurgical industries is now very extensive.

The following list gives some idea of its wide application:

**Anti-Abrasive Linings.**

- Skip and chute linings for sand, clay, ores, soft and hard sludge, and coal.
- Hopper linings and baffles in coal, ore, and wheat handling plant.
- Complete covering of agitators and thickeners.
- Ball and tube grinding mills.
- Mining dredges and dredge buckets, chutes, riffle tables, concentrators, and launders.
- Pump casing and impellers for gravel and sand.
- Sandblast cabinets, fittings and nozzles.
- Pipelines from gravel and sand pumps.

When designing rubber for abrasion resistance, the nature of the material to be handled must be carefully studied. It is necessary to have full details of its mechanical and chemical properties and the size of material to be handled, for the rubber used must have the following properties:

1. Resistance to cutting.
2. Resilience.
3. Resistance to tearing.
4. Withstand temperature fluctuations and small structural deflections.
5. Must age slowly against heat, chemical, and light conditions.

A very important point in connection with the use of rubber for abrasion resistance in place of special steels or stone is that rubber linings show a very big saving in weight. This means reduced structural costs and, in the case of moving plant, a reduction in the power of consumption.

To illustrate this section, a few examples of savings obtained with rubber abrasive resisting linings will be given.

1. **Pumps.**

   Rubber-lined pumps, manufactured by an Australian engineering firm, are in use at Mt. Lyell Mine, Tasmania, for the pumping of tailings. The following results with these pumps, in comparison with similar cast steel pumps on the same work, has been published:
Rubber: An Engineer's Material.

<table>
<thead>
<tr>
<th>Part</th>
<th>Rubber</th>
<th>Cast Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follower Plates</td>
<td>40,000 each</td>
<td>6,000-8,000 each</td>
</tr>
<tr>
<td>Liner Plates</td>
<td>Original still good at 90,000 each</td>
<td>13,000-16,000 each</td>
</tr>
<tr>
<td>Impellers</td>
<td>Average for six, 51,000 each</td>
<td>3,500-4,000 each</td>
</tr>
<tr>
<td>Casings</td>
<td>Four cases still good after 89,000 each</td>
<td>3,000-5,000 each</td>
</tr>
</tbody>
</table>

The breakdown of the rubber-covered follower plates and impellers in some cases were due to damage and not wear.

2. Ball Mills.

The rubber lining of ball mills has produced some remarkable results apart from the increase in life. The thickness of the necessary lining, in comparison with other materials, is so reduced that the capacity of the mill is increased. The decrease in weight of the lining has reduced the power required, and the deflection of the rubber so increases the surface of contact for grinding that more efficient and finer grinding is obtained.

The following are results of tests. Item C is quoted in a Bulletin issued by the Department of Mines in Canada.

(a) A rubber-lined ball mill, handling hot corrosives, had the lining replaced after seven years, due to concentration of wear on one spot near the discharge opening.

(b) The wear on a 36 in. x 36 in. mill, grinding white glaze, with a ¾ in. lining, after eighteen months was too slight to measure.

(c) Records kept in the operation of a tube mill, 22 ft. x 5 ft., grinding quartz-like rock to four mesh or finer, using twenty tons of 1¼ in. iron balls, reports a loss of 1.5 per cent in the liner in three months. The 1 in. rubber lining and the bars and bolts which held it in position weighed 3,800 lbs., replacing a 2 in. steel lining weighing 22,000 lbs. The increased capacity was 15 per cent. and the power saving 20 per cent.

3. Chutes, etc., on Dredges.

The following information has been supplied by Dredging Companies in the Malay States, on the comparison of weights and life of manganese steel and rubber linings in dredge work.
(a) Side Runs—carrying sand from screen to ore-saving boxes.
Rubber, 952 lbs.—Two years, no appreciable wear.
Steel, 2750 lbs.—Worn out twelve months.

(b) Tail Chute—carrying sand from saving boxes to dump.
Rubber, 383 lbs.—Two years, still good.
Steel, 2750 lbs.—Worn out, five months.

(c) Stone Chute—stones and oversize materials from screen to rear of dredge.
Rubber, 470 lbs.—Two years, still good.
Steel, 8800 lbs.—Worn out, one year.

(d) Pipes—sand from upper to lower boxes.
Rubber—Two years, no wear.
Steel—Worn out, five months.

These examples are typical of the value of rubber-lining parts subject to severe abrasion, and shows that

The reduction in weight allows a lighter and cheaper structural design.
Reduction in power costs,
Lower maintenance costs.
Less loss of production due to maintainance.

Chemical Plants.—The previous section dealt with rubber in its use as an anti-abrasive, but just as important is its use in the Chemical Industry, for rubber can be compounded to make it resistant to acid and alkali liquids and fumes, and as a protective coating to prevent the contamination of chemicals from their containers.

Depending upon the nature of the chemical in contact with the rubber, it is used as soft or semi-hard rubber, or in the form of ebonite.

To give some idea of the extent of its use in the chemical industry, the following list covers some of its more important fields of application:

General chemical plant and storage equipment for corrosive chemicals.
Bleaching and Dyeing Industries.
Pickling processes in the steel industry.
For galvanising and tinning.
Electroplating.
Paper manufacture.
Manufacture of explosives.
Water softening plants.
Mining and ore treatment plants.
Breweries.
Food industries—fruit and vegetable canning, sugar manufacture.
Acid storage tanks.
Fertiliser manufacture.
Textile treatment plants.

The great advantage of rubber as a protective material in the chemical industries is that the only limit to the size of its application is the possible limitation of fabrication of the load carrying framework which is rubber-covered. The plant which is to be rubber-covered is designed in mild steel.

Many special metals and alloys are used in these industries which have excellent resistance to corrosion, each within limited fields.

Chemical stoneware can be made to special shapes and limited sizes, but is liable to breakage by impact or sudden temperature changes.

Glass, enamel, or glass-sprayed steel can be used up to the limiting size of the enamelling furnaces. Chipping can only be repaired by returning to the enamelling furnaces.

Wooden vessels and lead-covered vessels also have very limited application.

Rubber and synthetic rubber linings can be made to withstand attack from most chemicals. It is not affected by sudden changes in temperature. It is easily repaired. The size of work is unlimited, and if the shape of the part is unsuitable for covering with sheet material it can be moulded to it, sprayed on, or the part can be covered by dipping in latex solutions.

The main limitation to rubber treatment for the chemical industry is the working temperature conditions. The general limitation is 150 deg. F., but by the proper examination of each individual problem, temperatures much in excess of this figure can be satisfactorily dealt with.

Apart from the chemical properties of rubber, other advantages of rubber-lined chemical vessels are that the surface can be made continuous, which facilitates cleaning, and reduces troubles due to leaky joints. Being tough, it will stand considerable abuse and is abrasion resisting.
Two examples of the life of rubber-lined plant which illustrates the satisfactory bonding of the rubber to the metal are:

(1) A hard rubber-covered centrifuge, which is handling weak acids, is in good condition after ten years’ use.

(2) A steel wire pickling plant, working at 212 deg. F., which is constructed of an acid-proof, brick lining imposed on a rubber sub-lining in a steel tank, is still in use after twelve years, whereas a previous construction of wood and brick gave only five years’ service.

Rubber-covered chemical plant is so extensively used that it is now including the following types of plant:

- Storage and process tanks and covers, valves, pipes and fittings.
- Pumps, fan, cyclones, exhaust flues, and bearings.
- Filter frames, screens, and scrubbers.
- Tank cars, drums, and barrels.
- Classifiers and settling tanks.
- Buildings, frameworks and floors.
- Rollers running in corrosive liquids.
- Paddle mixers and ball mills.
- Wire slings, buckets, trays, and hooks.

When it is proposed to use rubber protection against corrosion, it is essential to have close co-operation between the industry concerned and the rubber suppliers, with every detail of the working conditions being known to both so as to get the best and most satisfactory results from the rubber protection.

**Vibration, Shock, and Noise.**—The use of rubber for machinery mounting to eliminate vibration, shock and noise, has progressed to such an extent that very heavy machines are placed on the upper floors of buildings without risk of damage to the buildings by vibration, and without annoyance to the people working in the building.

In designing machinery mountings, the rubber must not only be sufficient to carry the load of the machine in compression or shear; it must be so proportioned that its action as a spring is suitable to overcome the natural frequency of vibration of the machine being mounted. The natural vibration of the machine may occur in several directions if there are unbalanced rotational forces or horizontal reciprocating parts. So that in designing rubber mountings, a careful analysis of the natural vibration of the machine in all directions must be made if satisfactory damping is to be obtained.
For light machinery, compression mountings can be used, but their use is very limited as considerable depth is required to allow sufficient deflection to reduce the natural frequency of the machine. The mountings generally used are of the shear type and made as sandwich type mounting, or of tubular construction. In either case, the rubber is bonded to the inside and outside plates.

*Rubber Bearings* are being increasingly used under conditions where ordinary bearings fail, such as in machinery which convey abrasive materials. They are of two types:

1. Cylindrical, spirally grooved, for slow speeds, heavy loads and forced lubrication.
2. Polygon shaped for higher speeds and lower loads.

Both are lubricated with water. Bearing loads up to 600 lbs. per square inch can be used, but normal loading is approximately 25-30 lbs. per square inch of projected area to prevent shaft deflection. The ratio of length to diameter is from 2½ to 5 to one. The co-efficient of friction decreases with the load. Any grit entering the bearing merely impresses itself into the rubber and rolls out into the water groove to be washed away. No scoring occurs, and the wear is very slow, the life of these being anything from 5 to 10 times that of white metal or bronze bearings. Shaft speeds are from 100 to 4,000 feet per minute.

*Pressings.*—A recent, very important use of rubber is the part it plays in making light metal pressings of aluminium and other soft metals. As shown in the properties of rubber, it is deformable, but not compressible. For making light metal pressings, a bottom die only is made. The top die consists of a rubber block contained on the four sides and top only. The metal sheet to be formed is placed on the bottom die and the rubber pad is pressed on to it; the portions of rubber striking resistance flows towards the parts with no resistance, causing the sheet metal to flow into the die cavities.

Apart from the reduction in die costs, this method of pressing prevents burring and scratching, which is very important in highly finished products.

*Building and Architecture.*—As the work of the engineer and architect are closely allied, a few notes on the application of rubber in buildings will be in order.

The prevention of noise, particularly in hospitals, is necessary. This has been accomplished by the use of rubber matting, either plain or sponge rubber backed.
The cleanliness of hospitals can be improved by the use of rubber-covered walls, covings and skirtings. These can be produced in suitable colourings; can be readily washed, and are not damaged when bumped by furniture and other fixtures.

In industrial plants, the buildings can be heat insulated with the use of rubber sheeting or proofed against corrosive fumes by the complete rubber-covering of the whole building.

In the fittings of offices, shops, flats and houses, the co-operation of the rubber manufacturer, engineer and architect has resulted in the development of many and varied articles which give comfort, afford protection from damage, improve sanitation, and generally add to the appearance.

Conclusion.—The engineering applications of rubber are so numerous that it is very doubtful if there is a complete list anywhere of its uses. It would be impossible in one lecture to outline the full scope of its use. However, the brief outline given of the nature of its mechanical properties shows that rubber is a stable material with properties of definite value. It is a material which fills certain structural requirements in machine design and, consequently, is of great value to the engineer.

The brief illustrations given of some of its applications are sufficient to show that its uses are very varied, and that it can possibly be used to advantage in many other ways.

If you stop for a moment to consider the parts of a motor car, a locomotive and its carriages, a ship, or even a bicycle, you must realise that the engineer has applied rubber to give comfort, to do work, to prevent shock and wear against movement and corrosion in all these methods of transport.

No mention has been made of the electrical industry, but that field alone has used the electrical insulating value of rubber to help along its enormous growth.

To conclude, engineers should remember that rubber is a material that must take its place among the things we use in our design every day if we are to get the most suitable materials for overall efficiency in our work.

The author wishes to record his appreciation to the Management of the Dunlop Perdria Rubber Co. Ltd. for permission to present this paper.
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