THE MANUFACTURE AND USE OF FRICTION MATERIALS

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Warren H. Atkinson

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Warren H. Atkinson

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Sincere thanks are also due to Mr. R. F. Kohr, Chief Engineer, whose knowledge of brakes and brake design is far above that of the author's. To Mr. Wesco, Superintendent, to the men in the plant, to the testcar drivers and laboratory assistants -- much credit for material, herein contained, is due.

FOREWORD

It is the purpose of this paper to convey to the reader some of the more important phases of the manufacture and use of friction materials.

Whole books could be written on practically each and every phase of this work. This paper covers only the major topics which have been encountered by the writer.

The secrets of developing materials for use on brakes have been, and are, closely guarded throughout the industry. There is very little interchange of ideas between various companies. This, of course, is applicable to a great number of industries, but seems to be especially evident in this one industry in particular.

For the past five years the author has done a great deal of development work, on practically all types of lining. A good share of the materials being sold by this company at the present time were developed in this period. For a year and one-half all testing of materials was done under the supervision of the author, who now has charge of material specifications and development work in this company.

It is the sincere hope of the author that the facts contained herein will enable the reader to realize the importance and problems of an industry which is so closely related to our everyday lives. Automobiles, aeroplanes and machines of all kinds are here to stay. This industry, which makes friction materials, is a vital factor in the safety of the peoples of the world.

-- WARREN H. ATKINSON
1936

NECESSITY FOR FRICTION MATERIALS

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Ancient records reveal that wheeled vehicles were in use as far back as 3800 B. C. Since that time, therefore, these same vehicles have been in use in hilly as well as level country. Quite naturally in the early use of such conveyances, they were drawn by ox-team or horses and the method of propellation was used in retarding speed or stopping the vehicle. Undoubtedly before brakes of any sort were used on these wagons, heavy loads made it impossible for the oxen or horses to adequately reduce the speed. This led to the invention of the first brakes, which took place thousands of years ago.

Probably the first brake was one in which a hole was provided in the wheel, between the hub and outer circumference. Through this, a stick was placed and could be used as a lever against the body of the wagon - thus locking the wheel. In descending a hill the wheel or wheels were locked, which exerted a retarding force or "drag", preventing the wagon from over-running the oxen or horses.

These crude solid wheels gradually gave way to the spoked wheels which we know today. These, in turn, were fitted with metallic bands or tires. Quite naturally it was discovered that a lever with one end dragging on this band would give a braking action. Fundamentally, this type of brake is still used on wagons. The majority of locomotives employ the same principle of applying a drag by means of a shoe pressed against the tire of the wheel.

In the early days of the automobile this principle was in use. It gradually gave way to the external band brake and still more recently to the internal expanding shoe brake, with which we are better acquainted.

From the time the lever was first used on the rim of a wagon wheel until the present day, the retarding force was primarily one of friction. In the first stages wood was used, then metal - which is still used on the vehicles mentioned above. These materials had objections and later years found leather being used, and then woven linings came into prominence which gradually gave way to the woven linings as we know them today as well as the other types to be discussed further on in this paper.

With the advent of the automobile, friction materials as such were in great demand. This demand is constantly increasing. In the mechanical building of a car today, friction in a bearing, etc., is cut to the minimum and rightly so; however, though friction is unwanted and an evil in one part of a vehicle, it is necessary for the whole - in brakes. Not only are brakes necessary for automobiles, but machinery of various types, aeroplanes, and numerous other pieces of equipment.

DEMANDS FOR FRICTION MATERIALS

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The demands made of friction materials have increased with their use. Let us confine our thoughts here primarily to automobiles.

Twenty years ago the average city allowed no speed in excess of 10-15 miles per hour. In fact, very few of the cars then in use would attain speeds in excess of 30 miles per hour. Quite naturally then the amount of kinetic energy stored up in one of these cars was small. In order to dissipate that energy and stop the car, each square inch of brake lining area had its share of work to do.

Let us assume for purposes of comparison - a car whose gross weight was 3500 lbs. This car travelling on open road, which 20 years ago were as good as our poorest roads of today, at a speed of 30 m.p.h. The kinetic energy of this vehicle would be as follows:

$$KE = \frac{1}{2} MV^2 \quad \text{where } M = \frac{\text{lbs.}}{32.2} \quad V \text{ in terms of ft./sec.}$$

$$= \frac{1}{2} \frac{(3500)}{(32.2)} \times (44)^2$$

$$= 105{,}221 \text{ ft. lbs.}$$

Let us also assume that this vehicle had external band brakes on the rear wheels. The lining used was 2 inches in width and each wheel used 40 inches of lining. The total surface area of lining was then 160 sq. in.

This lining in stopping the car from a speed of 30 m.p.h. then had to absorb the above energy, or each square inch of lining absorbed 657.6 ft. lbs.

Now to bring these figures up to date. A large car today will weigh 4200# gross, and this is not the heaviest. This same car will attain a speed unthought of twenty years ago. For purposes of comparison, let us assume this car is travelling at a speed of 90 miles per hour.

$$KE = \frac{1}{2}\left(\frac{4200}{32.2}\right) \times (132)^2$$

$$= 1{,}126{,}916 \text{ ft. lbs.}$$

This car has internal expanding brakes on all four wheels. Each wheel has 2 brake shoes to which lining is applied. The lining necessary for one brake (two shoes) is 2 inches wide and a total of 30 inches in length. This means then that the total lining area on this car is 240 sq. in.

On observation alone one can see the great increase in the energy of this car over the previous one, and yet the lining area increase is slight in proportion. Each square inch of this lining must absorb, in a complete stop from 90 miles per hour - 4700 ft. lbs.

Not only are these figures enlightening but the fact also remains that twenty years ago, one merely had to stop his car - very seldom was it necessary, and in a good share of cases it was impossible to decelerate at a rate in excess of 5 to 10 ft. per sec. per sec. Today the rate of deceleration must be much higher - in other words each square inch of lining today must not only absorb seven times as much energy as it did twenty years ago but must absorb it at twice the rate.

Is it any wonder, therefore, that serious consideration be given to brakes and brake lining if this condition is to exist? There is no doubt that it will not only exist, but that the demands on brakes and brake lining will increase.

TERMINOLOGY USED IN MANUFACTURE OF FRICTION MATERIALS

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<u>Asbestos</u>:- The term asbestos is used collectively to designate a group of silicate minerals, a grouping which is based more on similarity of physical properties than chemical composition. The outstanding physical characteristics of the minerals constituting the asbestos group are - fibrous texture and flexibility. This physical condition is accidental, being due to the exaggerated development in one direction only of the individual crystals forming the aggregate. The commercial value of asbestos is determined essentially by the length of its fiber and the degree to which it resists heat and acids.

The several varieties of asbestos found on the market can be classified broadly into two groups - the Amphibole Asbestos and Serpentine Asbestos.

Amphibole Asbestos is usually regarded as the lesser important of the two, owing to the deficient strength and flexibility of its fibers. It is, however, much more resistant toward acids. Its composition in the pure state is shown by the formula, $CaO \cdot 3MgO \cdot 4SiO_2$. It is usually found in admixture with small impurities, so that a typical analysis is as follows:-

Silica	57.00 per cent
Aluminum Oxide	0.90 " "
Iron Oxide	3.00 " "
Magnesium Oxide	22.80 " "

Calcium Oxide	13.40 per cent
Potassium Oxide	0.30 per cent
Sodium Oxide	0.60 " "
Combined water	2.40 " "

Serpentine Asbestos, or Chrysotile, occurs in small veins forming an irregular network in serpentine rock. Commercially this is the most important variety of asbestos. Its composition is that of a hydrous silicate of magnesia, which is shown by the formula, $3\ MgO \cdot 2\ SiO_2\ 2\ H_2O$. A typical analysis being as follows:-

Silica	40.50 per cent
Aluminum Oxide	1.10 " "
Iron Oxide	1.80 " "
Magnesium Oxide	41.00 " "
Combined Water	14.40 " "

This variety is found principally in Canada, Arizona, South Africa, Cyprus and Russia. Its great value lies in the physical state of the fibers, which, in addition to being of great length, have a silky texture and show great tensile strength and flexibility. It is, however, more readily attacked by acids and less heat resisting than Amphibole Asbestos. Its decreased resistance to heat is undoubtedly due to the high percentage of combined water which it contains. The chrysotile fibers begin to lose water at a very slow rate just above 600°F. At 1000°F about one-fourth has been driven off, and the rate of disappearance has increased. At 1200°F the water disappears rapidly. The fibers are close to glowing at this temperature. When cooled, the asbestos has been reduced to a fine white powder.

Chrysotile Asbestos is further classified as to length of fiber. The long fiber material is used in making asbestos yarn, the shorter lengths used in homogeneous masses for molded goods, and the floats, or very short fibers, usually cleanings from machines used in grading fibers, are used as a cheap inert filler material.

Asbestos Yarn:- Asbestos yarn is yarn consisting of: (1) asbestos fiber, (2) asbestos and vegetable fibers, or (3) asbestos and vegetable fibers, and wire.

The latter two are most common in the making of friction materials. While the asbestos fiber itself shows great tensile strength, a yarn of pure fiber shows very little strength and is also difficult to make because of the surface of the fibers themselves which show little tendency toward cohesion. Plain asbestos yarn, consisting of asbestos and vegetable fibers, is not any too strong for the purposes for which it is used and entirely unsuitable for heavy or "complicated" weaving processes. For these heavy woven materials a metallic asbestos yarn is used, lead - brass - copper - or zinc wire being twisted together with the plain asbestos yarn.

Asbestos yarn is made and graded as to "cut", "ply", and "grade".

"Cut" is a term indicating the size of asbestos yarn. The word "cut" preceded by a number indicates, in multiples of 100 yards, the yardage per pound of single ply yarn. For example, "10-cut" indicates that a pound of single ply yarn so designated measures approximately 1000 yards; "5-cut" indicates a yarn that measures approximately 500 yards per lb. Ply is a term used to indicate the number of strands of single asbestos yarn twisted together to form a heavier yarn. For example, a "2 ply - 10 cut" yarn indicates a yarn of two strands, each strand being 10-cut.

Standard specifications for Asbestos Yarns, ASTM Designation: D299-33, are as follows:-

Asbestos Content.

The asbestos content of both plain and metallic asbestos yarn shall conform to the following requirements.

Grade A-1	77 percent minimum
Grade A	80-85 per cent
Grade AA	90-92 per cent
Grade AAA	95-96 per cent
Grade AAAA	100 per cent minus, tolerating a trace of foreign matter.

Yardage or "Cut".

Permissable range of variation in yardage plus or minus 50 yards per pound over given cut number.

For purposes of this paper, all Asbestos yarn referred to is Grade A yarn, 10-cut. Where plain and metallic asbestos yarns are used, they will be referred to as such.

Asbestos Cloth:- As referred to in this paper is a square woven single ply fabric. Before weaving cloth from asbestos yarn, either plain or metallic, the yarn has to be twisted on twisters. The number of strands of yarn, or yarn and wire, being determined in advance. The yarn then has to be "warped", or wound on a mandrille in long lengths. The warp thread is the lengthwise thread in a piece of cloth and the number of warp threads per inch is previously determined and the warp dresser simply winds this given number of threads per inch over a mandrille of given length. This determines the width of the finished cloth. Yarn is also wound on "cops" or small spools to be used in the "shuttle" for the "filler" threads. The weaving is then done on a loom similar to looms used for weaving cloth of any kind of material.

Rubber:- Crude rubber is the dried product obtained from the coagulation of the sap of the rubber tree. Pure rubber has the formula C_5H_8. Crude rubber, which contains impurities, is furnished commercially in several grades. Those used most commonly in brake linings are:- Latex, Smoked sheets, Crepe rubber, and Powdered rubber.

Latex:- Latex is the name given the sap that exudes from the rubber tree. It contains foreign matter and is an unstable colloidal suspension. After collecting latex from the trees an anti-coagulant is added to prevent spontaneous coagulation. Ammonia, sodium sulphite, sodium carbonate, and formaldehyde are commonly used for this purpose. This more stable product is then diluted with water so that it has a rubber content of 15 to 20 per cent. The latex is then strained to remove foreign matter and is bulked in 50 - 100 gallon lots to insure greater uniformity. This bulked latex is then shipped for commercial use or coagulated and made into "Smoked sheets" or "Crepe rubber". The latex which will be referred to elsewhere in this paper is prepared as above but may vary in concentration from 15 to 70 per cent, although the most common concentration is approximately 30 per cent.

Smoked sheets:- Acetic acid is added to the latex and the whole is transferred into coagulating tanks, where it remains for several hours, until coagulation is complete. For the preparation of smoked sheet rubber the coagulating tanks are partitioned into small chambers, the depth of which are equal approximately to the width of the finished sheet and adjusted so that the dry rubber will be approximately 1/8 inch thick. After coagulation is complete the sheets are passed between rolls for the purpose of squeezing out as much serum as possible. The sheets are then passed through marking rollers, which imprint a "diamond" or "close-cut spiral" design on the rubber. The purpose of the design is partly to improve the appearance of the sheet, partly to increase the surface area for drying purposes, but chiefly to prevent the sheets from adhering and forming a compact mass during shipment.

The sheets are then washed with water and hung on racks to dry before being transferred to the smoke-house. Here they are subjected to a simultaneous smoking and

drying process. The temperature of the smoke-house is approximately 110°F. and a period of from seven to eleven days is necessary for the complete drying of the rubber. Cocoanut husk or hard-wood fuel is used as a source of smoke. After this process, the smoked sheet is ready for shipment.

The purpose of smoking is to render the rubber asceptic. It is evident that considerable serum is still present in the rubber and this is "smoked out" so as to prevent fermentation. It can be noted from the above operation that there is no grinding, or breaking down of the nerve of the rubber, in the preparation of smoked sheets. For this reason it is considered somewhat superior to crepe rubber.

Crepe Rubber:- The essential difference between smoked sheets and crepe rubber is the treatment they receive immediately after coagulation. In the manufacture of crepe rubber the coagulum is passed between rolls, rotating at uneven speeds, a stream of water impinging upon the rubber in the course of its passage between the rolls. In this manner the serum is completely washed out of the rubber and there is no necessity for smoking. The rubber has a crepe appearance, due to the shearing action which it receives as it passes between the rolls, which move at uneven speeds. This shearing action tends to break down the nerve of the rubber, resulting in a slightly inferior product to smoked sheets.

Powdered Rubber:- The rubber latex can be broken up into a fine spray which is allowed to fall a sufficient distance through heated air to permit coagulation, due to evaporation of water. A fine rubber powder is thus obtained.

Vulcanization:- This action is commonly referred to as curing. Physical or chemical changes are effected in rubber by the action of sulfur or its compounds which affect the tensile properties, resistance to oil, appearance, etc.

The theories of vulcanization are many. It would not be stretching a point to say that many papers, longer than the one at hand, have been written on this one subject alone.

Accelerators:- There are certain organic and inorganic substances which are added in limited amounts to rubber batches to speed up the cure of the compound. These may or may not injure the resulting product. The most important inorganic accelerators are certain metallic oxides, namely, litharge, lime, and magnesia. Of the organics, pages could be covered with their names. A few of the more prominent ones are zinc dimethyldithiocarbamate on a clay base, lead dimethyldithiocarbamate on a clay base, tetramethylthiuram disulfide, diphenylguanidine, piperdine, pentamethylene dithiocarbamate, and di- or tho- tolylguanidine. Accelerators, as such, play a more important part in the field of soft rubber goods than in heavily loaded compounds such as are used in making friction materials.

Inorganic Compounding Ingredients:- A short list of materials used is given below. An attempt to give specific reasons for most of these would be folly. A reason for the use of one particular material might be brought forth, based on several different compounds, only to be thrown out by testing subsequent batches containing the same material. Those that are most commonly used in friction materials are:-

Litharge	Barytes
Zinc Oxide	White Lead
Lime	Asbestine
Clay	Floats

Organic Compounding Ingredients:- Here again the same thing can be said as was said concerning the inorganics. However, certain known facts about drying or semi-drying oils prove definitely that they are more stable in a rubber compound subjected to high temperatures than some other organic materials. A partial list of those used is as follows:-

Asphalt	Graphite
Mineral Rubber	Drying oils
Glue	Semi-drying oils
Synthetic resins	Gas Black or Carbon Black
Coal dust	

Reinforcing Agents:- Certain materials previously mentioned distinguish themselves from the others in that they impart to the vulcanized product a property of great importance - toughness and resistance to abrasion. Carbon black is the best reinforcing material, with zinc oxide occupying second place. A combination of these two in the right proportions will show better resistance to abrasion than either one by itself.

Softeners:- It would be entirely impossible to disperse a large amount of dry mineral matter in rubber without the use of softeners. In order to have a uniform material, the rubber must actually "wet" the ingredients that are to make up the whole. Softeners help to distend the rubber and permit this wetting to take place. Oils, fatty acids, and some synthetic softeners are of particular help to the rubber manufacturer for this purpose. There are some "wetting agents" on the market which, while not technically considered softeners, perform the same function.

Weaving:- The process of weaving is essentially that of uniformly combining, mechanically, strands of yarn or similar material. In applying this term to the manufacture of friction materials - the yarn is either plain or metallic asbestos yarn.

Drying:- This is the method of extracting solvents or wetting agents. In weaving asbestos yarn quite often the yarn is wet with water so as to minimize the amount of dust. This moisture then must be removed before the finished cloth or tape can be impregnated with waterproofing agents.

Drying also takes into account certain materials which are mixed with solvents such as benzol or naptha. In order to process certain materials solvents are necessary, but must be removed before certain other processes can be applied to this material.

Treating:- This term is used in connection with water-proofing asbestos cloth or coating a finished product for the sake of appearance. In general treatments used as above are solutions, in benzol or naptha, of hydrocarbons, drying oils or synthetic resins.

Mixing:- The methods used in mixing various compounds are numerous. For the sake of brevity, let us assume this term where mechanical or chemical mixing of any sort is used. Under the various types of material this will be covered more completely.

Frictioning:- This process applies in most part to folded and compressed linings. Here again, this will be covered in detail later. The fundamental operation is one of impregnating and coating a piece of fabric with a film of uncured compounded rubber.

Slitting and Folding:- These also apply primarily to a certain type of material. Slitting refers to the cutting into strips of goods in process and folding is done where certain desired thicknesses are to be obtained.

Molding - Curing:- A true molding operation is one of filling out a mold cavity, under pressure, of material to be molded. In this paper, the term molding is not to be confused with the same term applied to iron and steel handling. Molding in the sense used here may be done in some cases with cold molds and in other cases in hot molds. These cases will be handled separately later. Curing is the vulcanization of rubber or polymerization of resins or oils. This is generally done with the aid of heat and in conjunction with the actual molding.

Baking:- In some cases the term baking is synonymous with curing. That is - the actual polymerization or vulcanization may be done in an oven at elevated temperatures. Generally speaking, however, it is done to carry the chemical reactions to an end point, which if done in molds might make processing costs prohibitive.

Grinding:- This term is used in this industry as in any other. As a general rule, grinding is done only to bring a finished product to a given size. In cases where the term is used in the sense of making small particles from larger ones, they will be dealt with later.

TYPES OF FRICTION MATERIALS

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Woven:- This type of material is basically a pure asbestos yarn woven to the proper thickness and width. After weaving it may be impregnated with oils, resins, etc., but it differs from other materials in that it is held together or "bonded" by mechanical means during its make-up.

Woven Molded:- This material is principally the same as above except that after impregnation, the material, general in segments, is actually compressed in a confined mold and at least partially cured in this mold so that its shape will be retained on removal from the mold.

Folded and Compressed:- This material has asbestos cloth, either plain or metallic, as a base. Rubber compounds are either frictioned or spread on this cloth or the cloth impregnated with synthetic resin. This in turn is folded or plied-up to the desired thickness and then compressed by means of rollers or other means. The material then is cured in molds or in long rolls. This type of lining lends itself to greater compounding variations but unlike woven material, the plies are held together by the bonding material instead of through mechanical processing means.

Molded:- This term is most generally used in speaking of a homogeneous mass of material molded to shape and density. There are molded linings which are bonded by rubber and possibly still more which use resins for bonding purposes.

Sheeter Stock:- This is a particular type of material mixed in more or less of a homogeneous mass but actually built up, during processing, in the form of large sheets. The manufacture of this is covered later in this paper.

Extruded:- This is a process whereby a homogeneous mass is actually squeezed through an orifice which makes a definite size of lining. Some materials which are termed molded are basically extruded linings.

Millboard:- This refers to a type of material where an asbestos millboard is saturated with oils, resins or rubber cements and molded to given size and density.

MANUFACTURE OF VARIOUS TYPES OF FRICTION MATERIALS

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Woven Lining:- There are several methods of weaving lining to a definite width and thickness. The

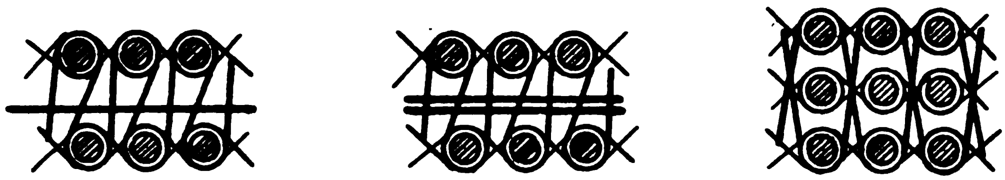


Fig. 1

actual method of weaving depends upon the set-up of the loom. Without going into too much detail on this particular part of making this type of material, consider the sketches in Fig. 1 as being typical types of weave.

As has been previously stated, and can be seen from above diagrams, a woven lining is held together by mechanical means - the various plies actually being tied together.

Woven lining is made principally in two distinct ways. The first, and probably the most common, consists of weaving a dry metallic asbestos yarn and subsequently saturating this tape with a filler and bonding material. Synthetic resins are being used extensively for this purpose.

The second method is to saturate each strand of yarn with a resin, or similar material, partially dry the solvents out so that the yarn is not too tacky to handle, and then weave the lining. In either case, the

lining is then calendared to thickness and width by passing through a series of rolls which compress the material and make it more dense. The treatment given the lining bonds it together more closely than could be done by using a nontreated tape. The bonding material also is used to vary the frictional characteristics of the lining.

The calendared tape is then either dried and wound in rolls of convenient length, or wound in rolls before drying, and is then ready for use.

Woven Molded Linings:- The above woven lining is made into woven molded lining merely by confining it in a mold where heat and pressure are applied simultaneously. This makes for an even more dense mass than an ordinary woven lining. While it is actually compressed the bonding material is set-up and there is slight chance of its springing back once this material is thoroughly cured. Woven molded linings are marketed in roll form, but for the most part are sold in segments of the proper length to fit a given brake shoe.

Folded and Compressed Linings:- The base material of this type of lining is a plain, single-ply fabric of asbestos yarn or metallic asbestos yarn. This generally is a coarsely woven material of 12 warp threads per inch and 6 to 8 filler threads per inch.

The warp threads are quite often wet with water to prevent dust in the atmosphere. Silicosis or Asbestosis are diseases which are common in the manufacture of any asbestos material where large amounts of asbestos dust are present; therefore to minimize this dust is to protect the employees. Wetting also ties in fuzzy particles

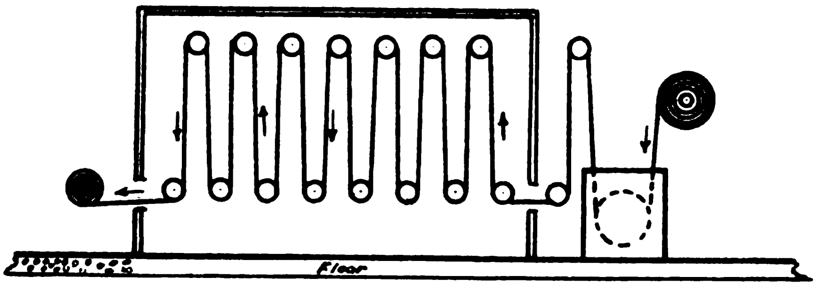


Fig. 2

of cotton or asbestos into the main body of the yarn, giving a more smooth yarn.

Particularly in the case of cloth which has been woven wet, this cloth must be dried before water-proofing takes place. Cloth woven dry has a tendency to absorb moisture, also. The common method of drying this cloth is shown in Fig. 2. The chamber is heated by steam or other means and circulation is provided to remove the steam from the air surrounding the cloth.

After the cloth is thoroughly dried, and quite often while it is still warm, it is run through a bath of water-proofing material. This is generally a solution, in benzol or naptha, of certain hydrocarbons, drying oils, or synthetic resins or mixtures of these.

After being treated in this manner the cloth must again be dried to remove the solvents. The dried-treated cloth is then ready for further processing.

Let us leave this water-proofed cloth at this point and consider the mixing of rubber compounds with which the cloth is to be frictioned, or coated.

Principally, there are two ways of mixing rubber compounds -- the Banbury mixer and milling. In the case of the Banbury mixer the principle is to mix in a confined space by means of spiral shaped rotors. Fig. 3 shows a cross section of this type of mixer. The clearance between the blades of the rotor and the sides is approximately 1/16th of an inch. Rotor A turns approximately 1½ revolutions to one revolution of Rotor B. This is a kneading action and is rapid as well as comparatively clean. The rotors, sides and bottom are jacketed and may be either heated or cooled as the case may be.

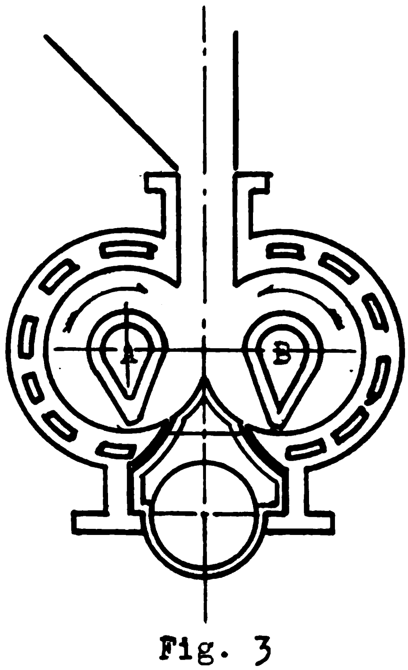


Fig. 3

The pure rubber, crepe or smoked sheets, is put in the mixer first and mixed until the mass becomes smooth. This is usually done in a warm machine which materially aids in warming up the rubber and in dispersing the compounding ingredients into the rubber. After the rubber is broken down sufficiently, the other minerals, softeners, accelerators, etc. are added until a smooth compound is obtained. This then is dumped from the machine by pulling out the movable bottom-piece, and the compound is slabbed out on a friction or even-roll mill.

The method of milling or mill-mixing a compound is principally the same as that of a banbury although the two processes are entirely different.

Fig. 4 shows a cross section of a mill. It is made up of two steel rolls which turn in opposite directions. In the case of a friction mill, the back roll turns 1½ times as fast as the front roll. This results in a grinding action which breaks down the rubber and also incorporates the filler materials.

The rubber is first warmed up and, when smooth, is allowed to form a coating over the entire front roll. The compounding ingredients are then dumped between the two rolls and mixing takes place. From time to time the operator must sweep up the material which sifts through between the rolls and is collected in a pan. These are put back until all ingredients are thoroughly incorporated.

An even-roll mill is used generally where a compound is to be sheeted to a definite thickness but where a grinding operation is not wanted. The construction of

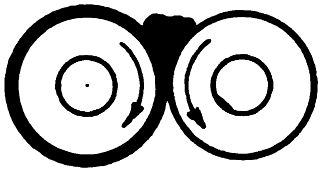


Fig. 4

an even-roll mill is the same as that of a friction mill except that both rolls turn at the same speed.

Certain folded and compressed linings are made by running the water-proofed cloth through a rubber cement. In this case the rubber compound is swelled with benzol or naptha to a predetermined viscosity and the cloth merely runs through this solution picking up compound as it goes. The solvents are then evaporated and further processing takes place as in the case of frictioned stocks.

Cloth is "frictioned" on a friction calendar which is constructed and operates as follows:-

Fig. 5 shows a cross section view of a calendar in operation. The calendar is comprised of three rolls, one on top of the other and nearly touching. If the top and bottom rolls turn in a counter-clockwise direction the center roll turns in a clockwise direction. The rubber compound is fed in between the center and top rolls. The center roll is completely covered with a thin film of compound, the thickness of which is determined by running the top roll up or down on a vertical axis. The center roll rotates 1½ times as fast as the top and bottom rolls, so that as the cloth passes through be-

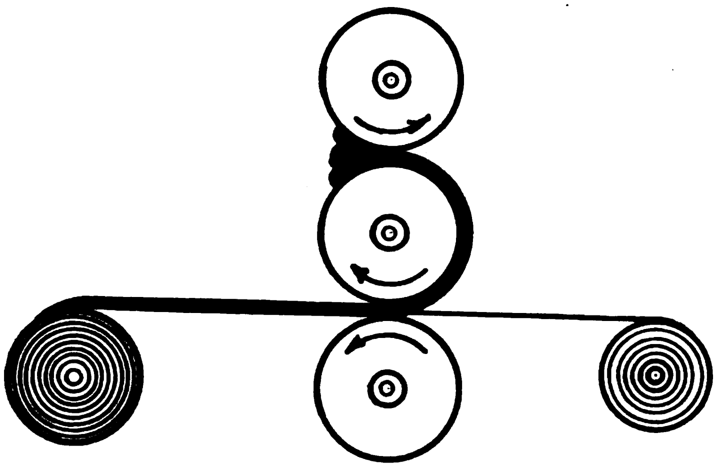


Fig. 5

tween the center and bottom rolls, travelling at the speed of the bottom roll, the compound is actually frictioned into every pore of the cloth. The pressure exerted by the bottom roll, which may be adjusted in the same manner as the top roll, determines the thickness of the frictioned cloth.

These rolls are hollow and may be heated or cooled as desired. Frictioning is generally done on rolls at a temperature of 150 to 190 degrees F. The bottom roll, however, generally runs cool so that the compound will have little tendency to adhere to it as it is pressed through the cloth.

From this point "spreader" stocks and "frictioned" stocks are handled in the same way.

Let us assume that a roll of cloth runs 48" in width and slightly in excess of 200 feet in length. In order to make a desired piece of lining, then, it is necessary to slit this cloth and fold it to approximate size.

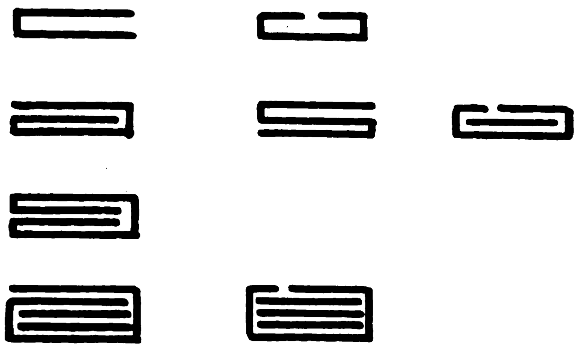


Fig. 6

For example:- Frictioned cloth will run .070" thick. To make a piece of 2" x 3/16" lining it is necessary to use three thicknesses of material. A piece 6" wide is slit from the original roll and folded twice to make a piece of lining two inches in width.

There are several ways of folding the material to obtain desired thicknesses. A few methods are shown in Fig. 6. After the material is folded it is run through a sizing calendar, a sketch of which is shown in Fig. 7. This material is then ready to be cured. It may be cured in long strips for roll lining, or confined in a mold to add to its density. As a general rule when it is made in roll form, the curing time is sufficient to completely vulcanize the rubber and yet have some degree of flexibility. Linings are cured at temperatures ranging from 200 to 320 degrees F., and from ten minutes to one hour, depending on the thickness of the finished product. In case a rigid segment is desired, the lining

is cured in a confined mold for a short period of time and then put in a former, which holds it to a desired radius, and baked in an oven. This leaves a dense piece of material and quite rigid in comparison

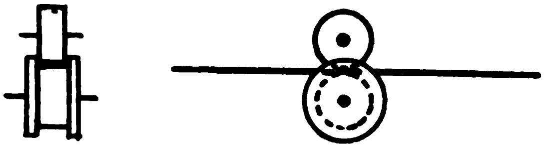


Fig. 7

with roll lining.

Molded Lining:- The term "Molded Lining" is applied to lining of a homogeneous nature. There are two distinct types of molded lining - (1) Rubber -- bonded, and (2) Resin bonded.

Several different methods are used in making linings of this type. Extruded stock, the manufacture of which is covered further on in this paper, is confined in a mold cavity and cured or may be baked in formers. The resulting lining is often termed molded when it primarily comes under the classification of extruded material.

Another method in making linings of this type is to mix the rubber compound with fairly long asbestos fiber and slab the resulting mass, cutting strips which are subsequently cured in a confined mold. The pieces after curing are then baked to radius, ground and packed for shipment. Rubber cements which are intimately

mixed with asbestos fiber have been employed to some extent. The solvent, used in making the rubber cement, is evaporated off and the remaining mass cured in a mold, radiused and baked.

Asbestos millboard has been employed to some extent in making "molded" linings. The millboard is saturated with a drying oil, rubber cement, or synthetic resin and the solvents are dried out. This is then cut into strips, cured in a mold, radiused and baked.

Mixtures of dry asbestos fiber, compounding ingredients, and pulverized synthetic resins have become more and more popular in making molded linings. In this case the ingredients are mixed in a ball mill. This machine is nothing but a cylinder rotating on a horizontal axis. The compounding materials are put in and a charge of porcelain balls, or wooden blocks, are added. As the cylinder rotates, these balls, rolling with the fiberous mass, mix the compound thoroughly. The material is then separated from the balls and is pressed dry, under enormous pressure, in a confined mold. Pressures of 2,000 to 5,000 lbs. per square inch of surface area are employed. These pieces may be pressed flat, curved or edgewise, as the case may be. Some of these linings are pressed into a wire screen or metal backing-plate, which contacts the brake shoe, thereby increasing the tensile strength insofar as shifting on the rivets in concerned. The pressed material is then baked to radius. In some cases combinations of synthetic resins and drying oils are used.

<u>Sheeter Stock Linings:-</u> In making this type of lining the process of mixing is similar to some types of molded lining. A rubber cement is mixed in a large churn, to which is added compounding ingredients, such as graphite, sulfur, etc. After completely mixing this cement it is run into a dough-mixer, or kneader, where it thoroughly coats the asbestos fiber. This dough is then sheeted on what is called a sheeter. (See Fig. 8) Small roll A is water cooled. Roll B is steam heated. The rolls run in opposite directions as shown.

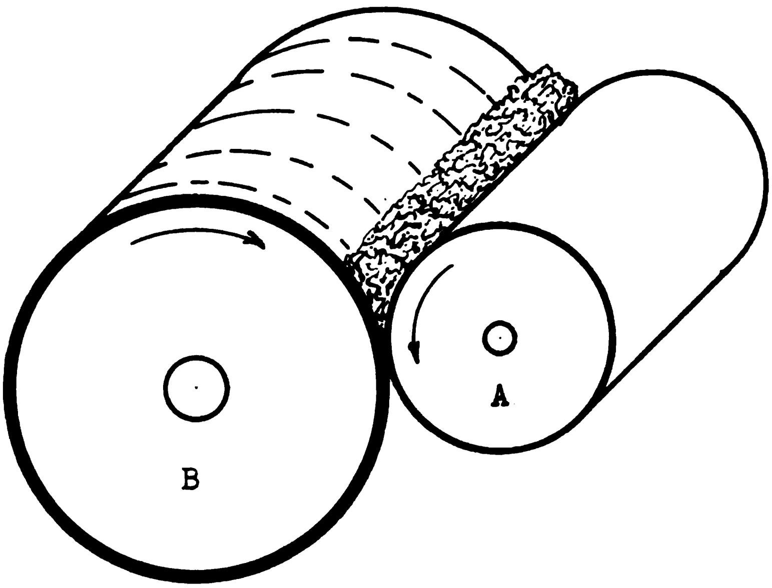


Fig. 8

To sheet lining on this machine, roll B is covered with a rubber cement. The dough, as spoken of above, is then evenly distributed in the "V" groove between the two rolls. As the rolls turn, the compound is built up on the large roll and is partially cured due to the hot roll. As it builds up on this roll, the small roll automatically moves away from the large one. This tends to spread or sheet the stock on to the large roll in thicknesses of .002" - .003" per revolution. When the desired thickness of material has been built up on this roll, the machine is stopped and the sheet removed. This in turn is cut into strips of proper width. These strips may be rolled and sold in that form, or segments may be cut and baked to radius. The baking tends to harden the material so that it will hold its shape, presenting a molded lining appearance.

Extruded Lining:- The mixing of material for this type of product is similar to mixing for a molded type of lining. The rubber cement is mixed and this then is used in coating the asbestos fiber. In the case of this type of material, the rubber-phase must be fairly large. This is to permit the material to be extruded on a machine such as is shown in Fig. 9. The mass of material is fed into the machine and by means of a screw is uniformly forced through an orifice which corresponds to the size of the lining desired. The strength of this material, which contains solvents, is

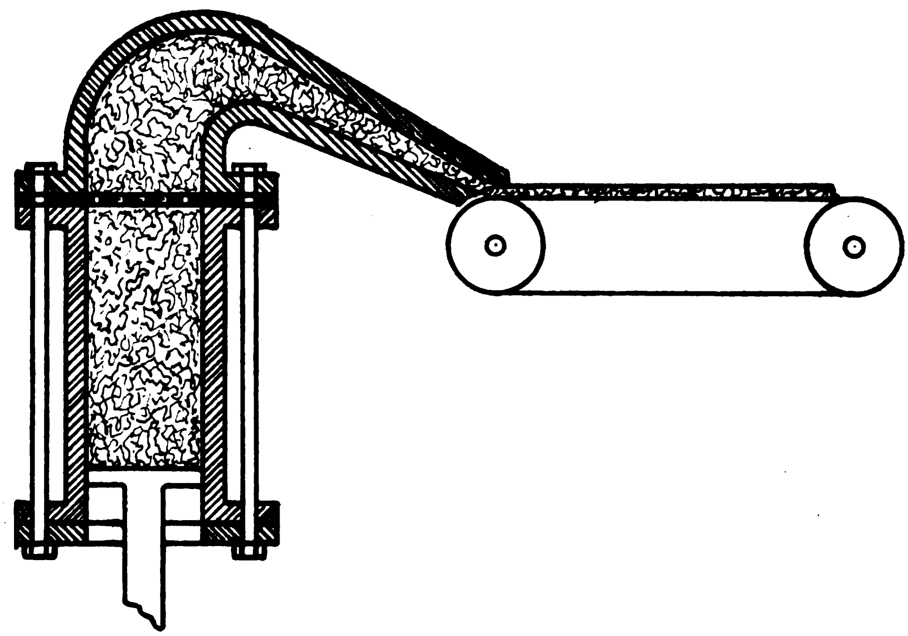


Fig. 9

low. Due to this inherent weakness at this stage it is carried away by means of an endless belt and partially dried. This is then rolled and further dried in ovens. The material is then cut to given lengths and baked, or may be cured in flat strips and sold in roll form.

DISCUSSION OF VARIOUS TYPES OF FRICTION MATERIALS

The advantages claimed for the above types of lining are numerous. Quite naturally there are advantages and disadvantages to all types, either due to physical characteristics or manufacturing limitations.

Woven lining has good tensile strength, which is an advantage. The limitations lie mostly in frictional characteristics. Due to the method by which this tape is treated, great changes in frictional qualities cannot be made. The saturant, or treatment, must have penetrability in order to coat the tape thoroughly from one exposed surface to the other. In order for a saturant to coat a material of this kind, it cannot be too heavily loaded with pigments. The tape itself acts as a filter for the pigments, leaving heavily pigmented material on the outer surfaces and practically no pigment on the inside. This, of course, cannot give uniform performance as the lining is worn away. This, however, does not apply in the same respect to yarn saturated before weaving of the lining.

Woven molded linings have much the same limitations and characteristics as woven lining. The molding operation, however, does increase penetration, which results in a stronger, more dense and more uniform material.

Folded and compressed linings, due to the method of manufacture, can be varied in properties considerably. The asbestos cloth, which is the base of this type of lining, gives a definite amount of tensile strength. This allows the compound to be varied more than could be done with materials whose strength depends on the compound alone. This rubber compound must be of such a nature that it can be frictioned on the cloth. It also must be sufficiently adhesive that the plies will bond together securely, and the resulting lining must of necessity have the right frictional properties. Quite often folded and compressed linings fail due to ply separation. The bonding material is weakened with use or softens at operating temperatures, thus weakening the cohesion between the plies, allowing them to separate. This material is often criticized because of its compressibility on the car, which is due to porosity, or lack of density, in the finished material.

Molded linings are being used, possibly more than any other type. This is due to their homogeneous structure. If the material is properly compounded it should be more uniform than any of the aforementioned types. There are no plies through which, as the lining wears out, a corresponding change in friction is encountered. Molded material must be bonded together sufficiently to give adequate tensile strength and the bonding material must be of such a nature that it will not soften under extreme temperatures or failure occurs.

Infusible synthetic resins are being used extensively as a bonding material, because of their characteristic of carbonizing before plasticizing. A thermo-setting or infusible resin, when completely polymerized, will not soften down due to additional heat, as will some rubber compounds. Some of the natural resins found in rubber are thermo-plastic in that they will soften at elevated temperatures. If compounding ingredients are used which will make thermo-setting resins of these, a good molded material can be secured which has rubber as a binder.

Sheeter stock linings have definite processing limitations. Large amounts of compounding ingredients cannot be thoroughly wet by the rubber cement and still allow it to have enough adhesiveness to bond the asbestos fiber. A certain amount of plastic strength is necessary in order to process material in this manner. Extreme heat will cause this material to fail if not properly compounded. Whereas the plies in this type of lining are only thousandths of an inch in thickness, they must bond themselves together tightly in order to preclude separation.

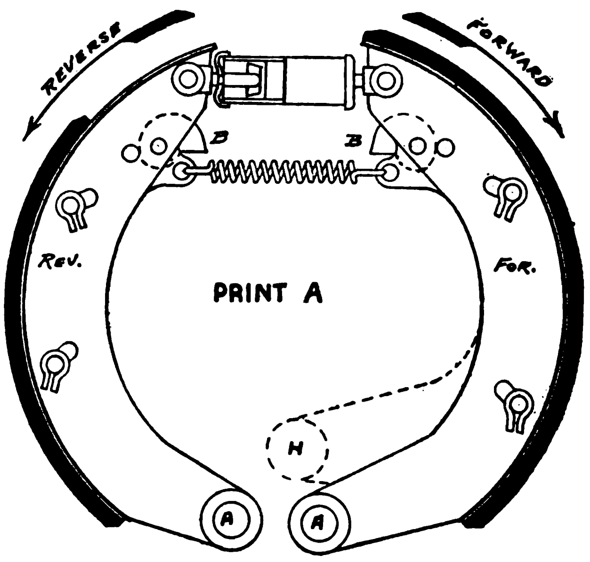
Extruded linings are homogeneous in nature but are limited due to methods of manufacture. The consistency of the stock, as it is being extruded, must not vary, nor is it possible to extrude materials which are vastly different in consistency. Too much long fiber asbestos cannot be used or the material will not extrude uniformly or properly.

Millboard types of lining present somewhat the same objections as woven lining. The saturant must thoroughly penetrate the millboard in order to make a uniform material. In some cases compounding ingredients are mixed with the asbestos before the millboard is made, which makes for a more uniform product.

Much more could be said in regard to the advantages and disadvantages of these various types of material. The above brief comparisons give an idea as to some of the things that must be taken into consideration in dealing with certain kinds of lining.

It must be remembered, however, that if the material is properly compounded -- any of the above types of lining will give satisfactory performance.

TYPES OF BRAKES



LOCKHEED HYDRAULIC BRAKES

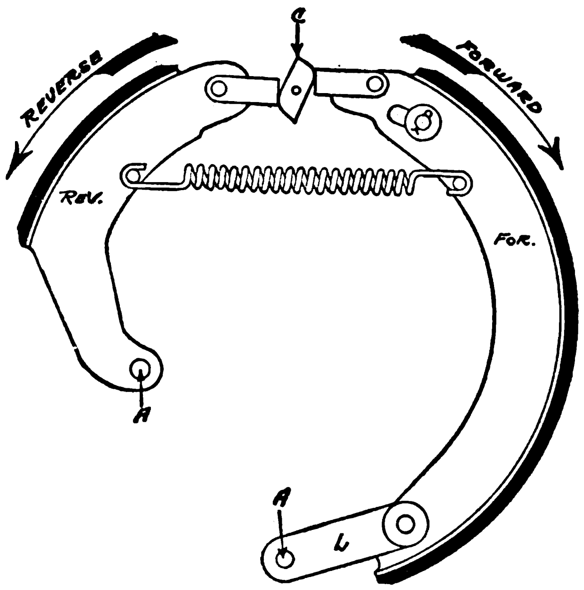
The Lockheed Hydraulic brake system is composed of a master cylinder in which the hydraulic pressure is originated, a cylinder operating the brake bands or shoes on each wheel drum, a supply tank by which the operating fluid in the system is replenished, and the line, consisting of tubing, flexible hose and brackets interconnecting the master cylinder, wheel cylinders and supply tank.

There is no pressure in the system when the foot pedal is in the off position, except a small residual pressure determined by a spring-loaded check valve in the master cylinder. This pressure is maintained for the purpose of guarding against the possibility of creating a vacuum which would draw air into the system past the wheel cylinder cups. When pressure is applied to the pedal, the master cylinder piston, with which the pedal is mechanically connected, is forced inward and causes the fluid to flow through the entire line, the pressure created in the master cylinder being transferred into each wheel cylinder with equal and undiminished force. The column of noncompressible liquid entering the wheel cylinders between their opposed pistons causes the pistons to move outwardly and against the pressure of the retractor springs. By means of a mechanical connection between pistons and brake shoes, these are brought into contact with the drums and the pressure on all four wheels is absolutely equalized.

When the pedal is released the retracting springs force the wheel cylinder pistons to their original off position and the liquid is forced out of the cylinder and back into the line. This, with the master cylinder return spring, forces the master cylinder piston backward and in position for pressure to be applied again.

As can be seen from the above diagram, this brake consists of two shoes. These shoes are fastened to the backing plate at the heel end of the shoe, by means of eccentric anchor pins. The toe ends of the shoes are fastened to the piston rods of the wheel cylinder. Eccentric adjustments are provided at point "B" in order to adjust the brakes to proper clearance from the drum. The webs of the shoes are located from the backing plate by means of pins, over which cotter pins fasten, in order to keep the shoes in a definite plane.

The self-energizing effect of this brake depends on the location of the eccentric anchor pins. This is designed in the brake to give the best performance. Should the anchor pin be shifted from position "A" to position "H", the brake would be much more effective and might even become sensitive with a slight change in coefficient of friction of the brake lining.

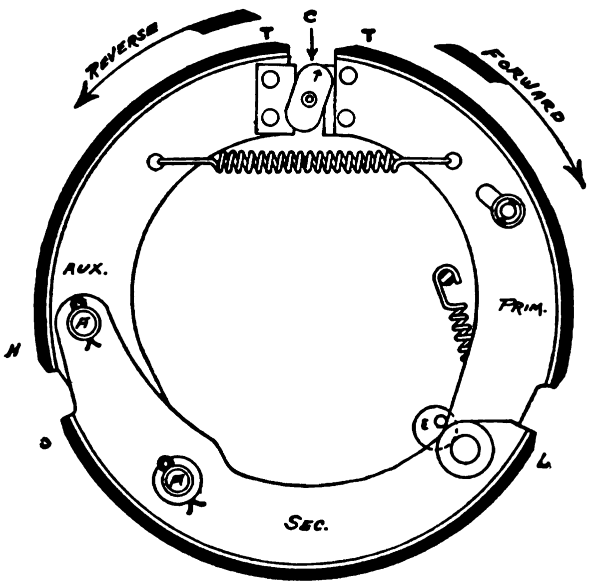


HUCK BRAKE

Some of the details of construction may be seen in the above diagram. The forward (long) shoe anchors against the backing plate through the medium of a link "L" which is articulated at both ends. The center of rotation of this link is such that when the brakes are applied with the drum revolving in the ahead direction, it tends to swing the shoe into tighter engagement with the drum. This produces a high degree of self-energization but since the arc of movement (due to the two-point articulation) is approximately parallel to the drum raceway there is a reduction of the tendency towards excessive heel or toe contact to which highly self-energized shoes are susceptible.

In the later designs of this brake, the reverse shoe is made interchangeable with the forward shoe. This aids in decreasing localized pressure on the drum which tends to make the drum oval-shaped.

The latest types of this brake employ hydraulic actuation by means of a master, and wheel cylinders. Rather than use eccentrics at the toe end of the shoe, such as employed in the Lockheed hydraulic brake, the piston connecting rods on the wheel cylinders are threaded into end caps. The toe adjustments are made by rotating these end caps.

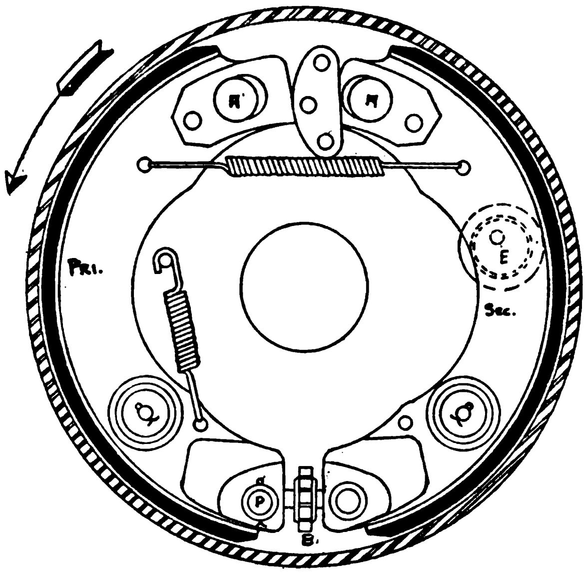


BENDIX THREE-SHOE BRAKE

These brakes are of the mechanically operated internal type. The brake assembly for each wheel comprises three shoes (primary, secondary and auxiliary) so constructed and actuated as to give a servo or self-energizing action. One end of the primary shoe bears against the operating cam. The other end is connected to the secondary shoe by means of an articulating pin. This articulating pin engages (but is not rigidly fastened thereto) an eccentric pin attached to the backing plate in such a way as to form an adjustment to compensate for secondary shoe lining wear. The secondary shoe is hinged at one end to the primary shoe as shown above, and is anchored to the backing plate at its other end. Acting independently of these two shoes, the auxiliary shoe is anchored at one end to the backing plate while the other end bears against the operating cam.

The primary and auxiliary shoes are both held against the operating cam by means of a tension spring known as the P & A spring.

When the brake is applied the operating cam pushes the primary and auxiliary shoes against the drum. The primary not being anchored is free to move and is dragged by the contact with the drum in the direction of the drum or wheel rotation. This movement of the primary shoe forces both itself and the secondary shoe more tightly against the drum and thus increases the pressure by supplying a self-energizing action. Actually the pressure on the drum caused by this energizing action is much greater than could be exerted by hand or foot through the levers and cams.



BENDIX DUO-SERVO BRAKE

(Double Anchor Type)

The Bendix "Duo-Servo" model brake is of the two-shoe internal type mechanically operated by either levers or cables. It differs from previous models of the same make in that it has equal energization in either forward or backward movement of the car, and also in the details of the shoe mountings and methods of adjustment.

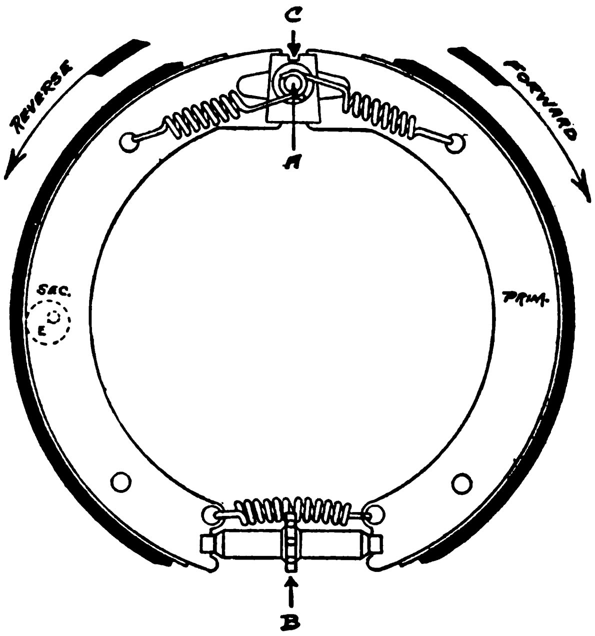
The two shoes in each brake assembly are identical in every respect and fully interchangeable. They are linked together at the lower end by a right and left hand threaded screw ("B" in the above diagram) through articulating pins. At the upper end of the shoes are two anchor pins ("A" in above diagram) one of which serves for the anchor for braking in the forward direction and the other as the anchor for braking in the reverse direction. The shoes are expanded against the drum by means of a floating cam. Two cam trunnion blocks bear on the curved ends of the shoes and provide ample wearing area at the points where effort is applied.

There are three points of adjustment, all of them being made from the frame side of the backing plate as follows:

> The right and left hand threaded screw "B" which serves as an adjustment for clearance between the lining and drum.
>
> The eccentric adjustment "E" which centralizes the shoes in the drum and prevents dragging when brakes are released.
>
> The anchor pins "A" which enable setting of the shoes to provide proper relative toe and heel contact between lining and drum; the slightly elongated holes in the backing plate permit this movement of the anchors.

The cam lever which is mounted on the serrated camshaft allowing the lever to be moved to take up any wear in the linkage. The cam lever adjustment is used only on models with lever control.

This double anchor type has been largely superseded by the single anchor model, described on the following several pages.



BENDIX DUO-SERVO BRAKE

(Single Anchor Type)

This type differs from the double anchor type in that but one anchor is used and the application is by means of an "equal action" (lift) cam which floats on the anchor.

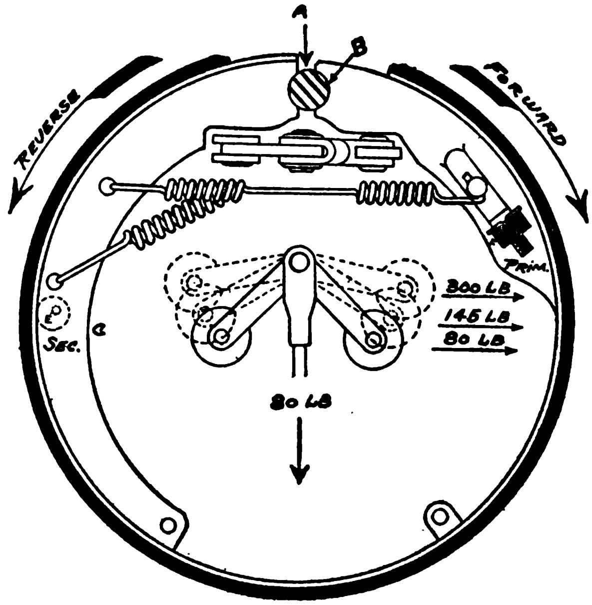
In this brake, the retractor springs are fastened from the shoe to the end of the anchor rather than being fastened together by one spring. The bottom ends of the shoes are held together by means of another spring which also acts as a stop for the ratchet adjusting screw.

The spring which holds the secondary shoe in contact with the cam is stronger than that which holds the primary shoe. This allows the primary shoe to move outward into the drum ahead of the secondary. In this duo-servo brake, whether it be single or double anchor, the primary shoe activates the secondary when the brake is applied as the car is going forward. The exact opposite is not true when the car is moving in reverse, due to the difference in spring tension. Because of this duo-servo action and also the fact that this brake has more self-energization, the rigidity of the brake shoe itself has a definite bearing on performance of the brake. If the web of the shoe is not very deep, an enormous increase in action is effected, while if the web is too deep (making a more rigid shoe) the self-energizing and duo-servo actions are materially decreased. The rigidity or flexibility of the shoes also affect the wear on the lining. A more rigid shoe will wear more at the center, and the opposite is true of a flexible shoe. This must be, and is built into the original design of the shoe.

The later models of this brake are hydraulically operated. Hydraulically, the design of the duo-servo hydraulic combination is the same as the Lockheed model previously described. The shoes and backing plates are similar in design to those mentioned above.

Where hydraulic actuation is used, mechanical means are employed for use of the emergency brake, on the rear wheels.

In some instances, a single piston wheel cylinder is used rather than the double piston type used on Lockheed brakes. In this case the cylinder is rigidly fastened to the secondary shoe and the piston connecting rod to the primary. An elongated hole in the backing plate, through which the line is connected to the cylinder, allows movement of both shoes.



STEELDRAULIC BRAKE

Steeldraulic brakes are of the mechanical internal self-energizing type. No equalizers are used in any of the steeldraulic installations. Operating means is by flexible members or so-called vertebrae held between coils of a spring, the whole being enclosed by a waterproof conduit which contains the grease lubricant.

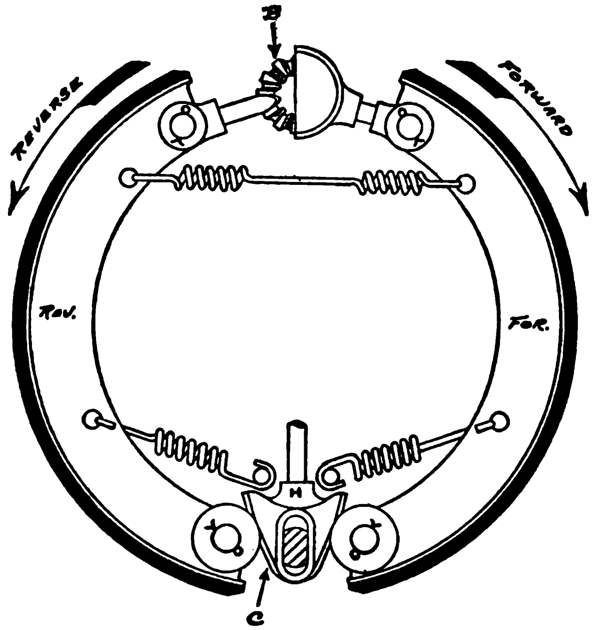
The control used is of the cable-conduit type. This control consists of two principal elements, a tension element, which is the cable, and a compression element, which is the conduit.

The band, although of one-piece construction, is a combination of rigid and flexible sections. (See above figure). The purpose of the flexible or inflanged section is three-fold; first, to exert a retarding force against the rotation of the drum; and, second, to impart to the assembly the ability to adapt itself to variations in drum diameter. The third function of the unflanged section is to deliver an energizing force to the flanged section.

The expanding movement of each band is approximately one-eighth as great as the pedal travel.

Toggles are used throughout for operation of the band assemblies. This is shown in the center of the brake diagram. The more powerful leverage action caused by flattening of the toggle through the wearing of the lining is partly compensated by the arrangement of the brake linkage, which is designed so that mechanical advantage is lost as the toggle gains it.

The toggles are equipped with stops to prevent them going past center which would lock the brake. If the toggle unit is incorrectly assembled the stop becomes inoperative.



FORD BRAKE

Some of the details of construction of the Ford Brake may be seen in the above diagram. This brake is of the two shoe internal expanding type.

The brake is operated by means of a wedge "H" at the bottom, expanding the shoes outward against the drum. The shoes ride on this wedge by means of rollers fastened to the end of the shoe. This wedge, in turn, has an elongated hole which permits movement on the wedge bolt fixed to the backing plate. This movement of the wedge is confined to a definite plane which causes both shoes to move outwardly at the same rate and equal distances. To the other ends of the shoe are attached rods which pivot on the shoe and also afford means of adjustment by rotating the adjusting screw "B". The rear brake (diagram not shown) used in connection with the front brake pictured above, is operated by means of a cam in place of the wedge.

In the later models of this brake, wedges are used to operate the rear brake shoes instead of the cams. The wedges at front and rear are of the "floating" type to impart a self-centering action. Both shoes are now energized due to the fact that the wedge bolt does not act as an anchor. The use of these wedges all around provides equal speed of application at front and rear brakes and eliminates the necessity of backing off the rear brakes after adjustment is made.

LININGS FOR DIFFERENT TYPES OF BRAKES

In general, the following facts are true:

Brakes requiring a high friction lining:

All external band brakes.

Lockheed hydraulic brake.

Huck brake.

Brakes requiring a medium friction lining:

Bendix three shoe brake.

Steeldraulic brake.

Brakes requiring a low friction lining:

Bendix duo-servo brakes.

In some instances a high friction lining which has a certain amount of compressibility does not give as good results on a car as a lower friction material with less compressibility. Combinations of high and low friction materials are quite common, in which case a high friction material may be used on the forward shoe and a low friction material on the reverse shoe.

Certain cars using hydraulic brakes employ wheel cylinders of the same size on front and rear brakes. Other cars use larger wheel cylinders on the front brakes than on the rear. In order to obtain the best results with the former type, a higher friction material is used on the front brakes than is used on the rears. In the other case, the same lining may be used on all four wheels .

SOME CONCEPTS OF FRICTION

COEFFICIENT OF FRICTION

"In order to compare the frictional resisting properties of various pairs of materials or of the same pair of materials under varying conditions of their surfaces of contact, and in order to calculate the maximum frictional force corresponding to any normal pressure, a certain experimental constant, called "the coefficient of friction", is used.

"The coefficient of static friction for any two surfaces is defined as the ratio of the limiting friction to the corresponding normal pressure.

"If two surfaces move relative to each other, the ratio of the friction developed to the corresponding normal pressure is defined as the coefficient of kinetic friction.

"The results of the experiments of Morin on dry surfaces, published in 1831, may be stated as follows:

1. The coefficient of friction is independent of the normal pressure.
2. The coefficient of friction is independent of the area of contact.
3. The coefficient of kinetic friction is less than the coefficient of static friction and is independent of the relative velocity of the rubbing surfaces.

"From experiments made by Tower, Goodman, Thurston, and others, on lubricated surfaces, it has now been found that the laws of friction for lubricated surfaces are almost the reverse of those stated for dry surfaces. For example, it is found that the friction of two surfaces is almost independent of the nature of the surfaces and of the normal pressure so long as there is a film of lubricant between the surfaces. Again, for lubricated surfaces, it is found that the friction is materially affected by the temperature, which is not true in the case of dry surfaces."

The above paragraphs are copied from "Analytical Mechanics for Engineers" by Seely and Ensign, pages 128-135.

Undoubtedly since this book was written, much work has been done along this line. The present theories of coefficient of friction do not accept the above laws as being absolutely true.

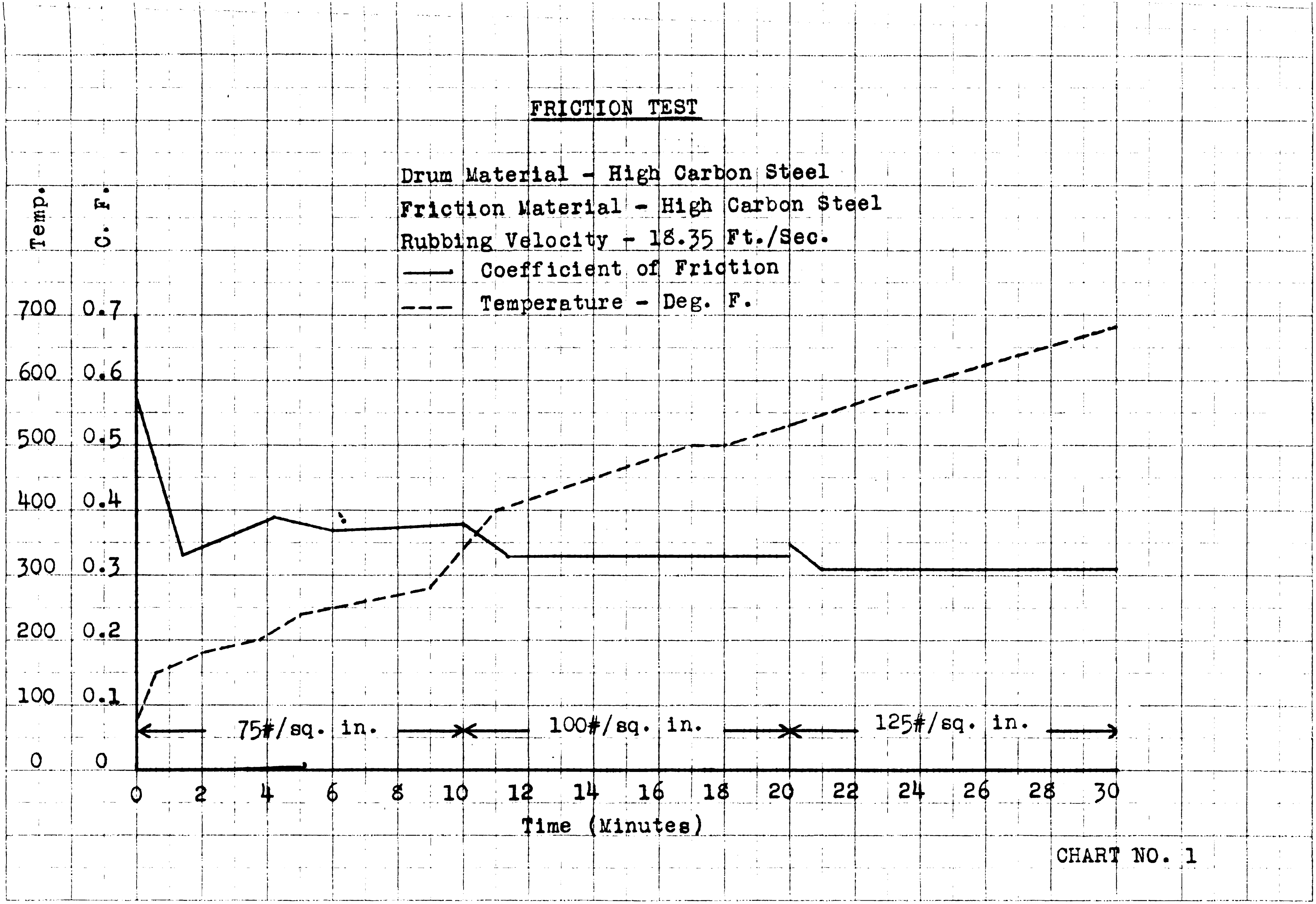
In the accompanying charts are indications that the above statements regarding coefficient of friction are untrue. All of the data given were obtained by using one type of friction testing machine. (The "Button Machine", described in detail later in this paper.)

Before concerning ourselves with friction materials such as are commonly used, consider the variations of friction of steel and cast iron which are commonly used in brake drums.

Chart No. 1 shows the variation of friction of steel against steel.

Chart No. 2 shows the variation of cast iron against cast iron.

Chart No. 3 shows the variation of steel against cast iron.


FRICTION TEST
Drum Material - High Carbon Steel
Friction Material - High Carbon Steel
Rubbing Velocity - 18.35 Ft./Sec.
Coefficient of Friction
Temperature - Deg. F.
Temp.
C. F.
700 0.7
600 0.6
500 0.5
400 0.4
300 0.3
200 0.2
100 0.1
0 0
75#/sq. in.
100#/sq. in.
125#/sq. in.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Time (Minutes)
CHART NO. 1

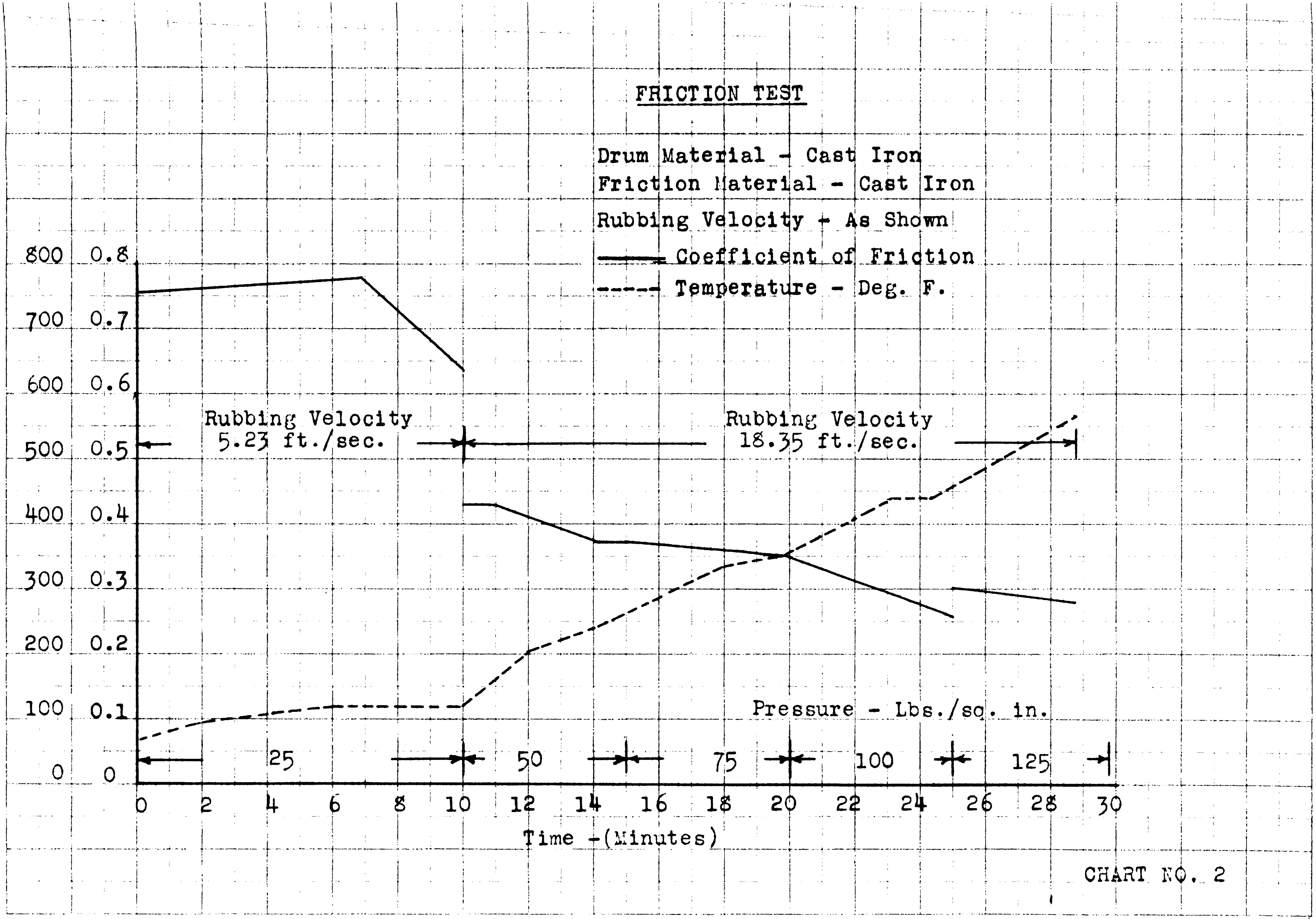
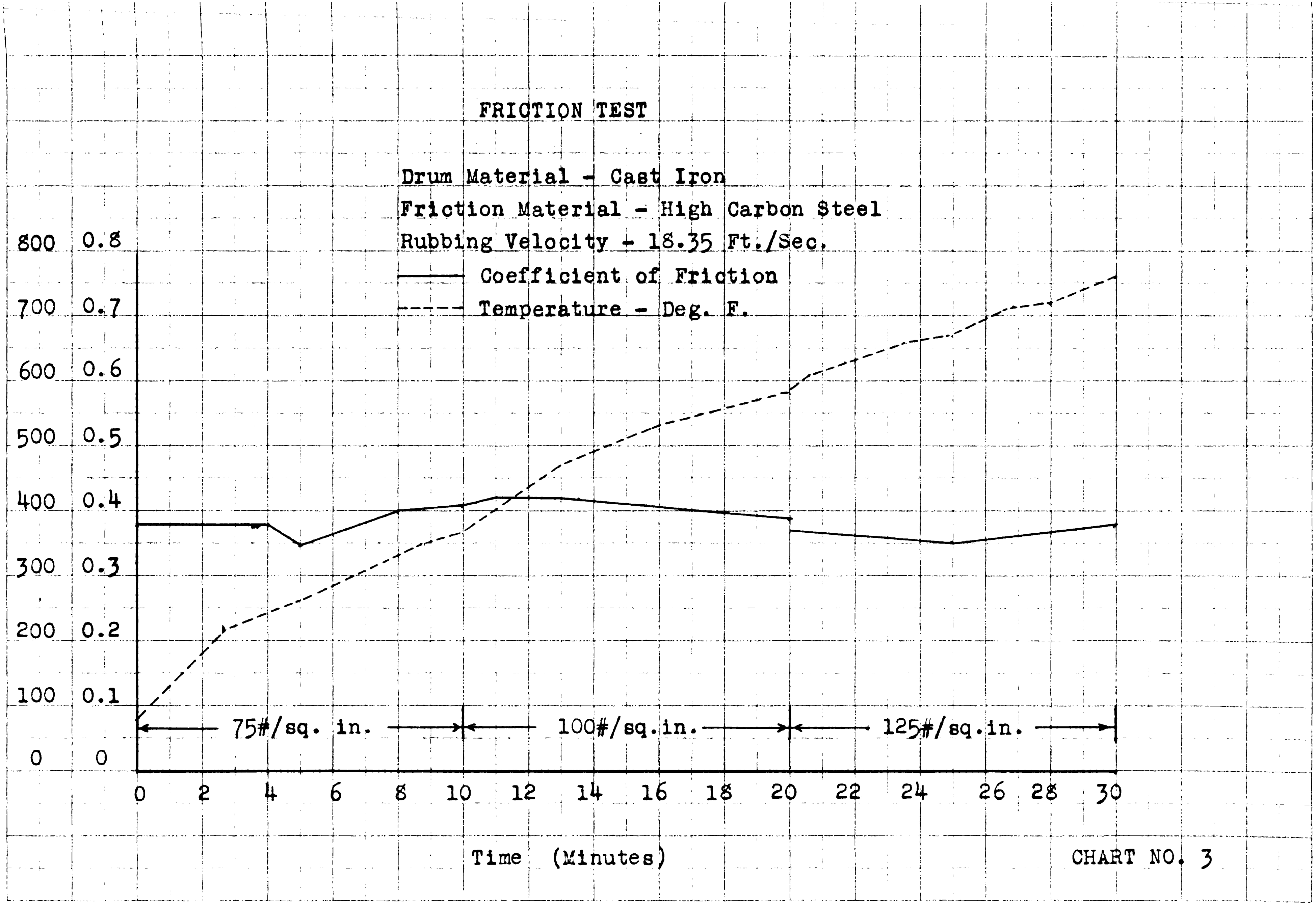

FRICTION TEST
Drum Material - Cast Iron
Friction Material - Cast Iron
Rubbing Velocity - As Shown
Coefficient of Friction
Temperature - Deg. F.
Rubbing Velocity 5.23 ft./sec.
Rubbing Velocity 18.35 ft./sec.
Pressure - Lbs./sq. in.
25
50
75
100
125
800 700 600 500 400 300 200 100 0
0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Time -(Minutes)

CHART NO. 2



FRICTION TEST
Drum Material - Cast Iron
Friction Material - High Carbon Steel
Rubbing Velocity - 18.35 Ft./Sec.
Coefficient of Friction
Temperature - Deg. F.
800
700
600
500
400
300
200
100
0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
75#/sq. in.
100#/sq.in.
125#/sq.in.
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Time (Minutes)

CHART NO. 3

Let us now consider some characteristics of friction material such as is used on present day cars.

The material, on which data is shown, is of a homogeneous nature using fine particle size (200 mesh maximum) compounding ingredients. The lining as tested, compresses but 1% in thickness when subjected to a button of 1/2 square inch area carrying a load of 3,000 Kg. From this then, it is inconceivable that the small pressures, under which the tests were run, could compress this lining sufficiently to cause the wide variation in coefficient of friction.

The material on which these tests were run, will lose but 2% to 3% of its weight when subjected to a temperature of 600 deg. F. for three hours. This should eliminate the theory that volatile matter escaping from the lining is responsible for the changes in friction.

Possibly an idea has arisen that increased rubbing velocity produces a glaze on the surface of the lining, which might decrease the friction, or that this increased velocity is accompanied by an increase in wear which might cause an increase in friction. In one case, (Chart No. 4), at 50 lbs./sq. in. pressure and a temperature of 600 deg. F., an increase in velocity shows a sharp decrease in friction. In another case, (Chart No. 5), at 50 lbs./sq. in. pressure, and at a temperature of 300 deg. F., an increase in rubbing velocity shows an increase in coefficient of friction.

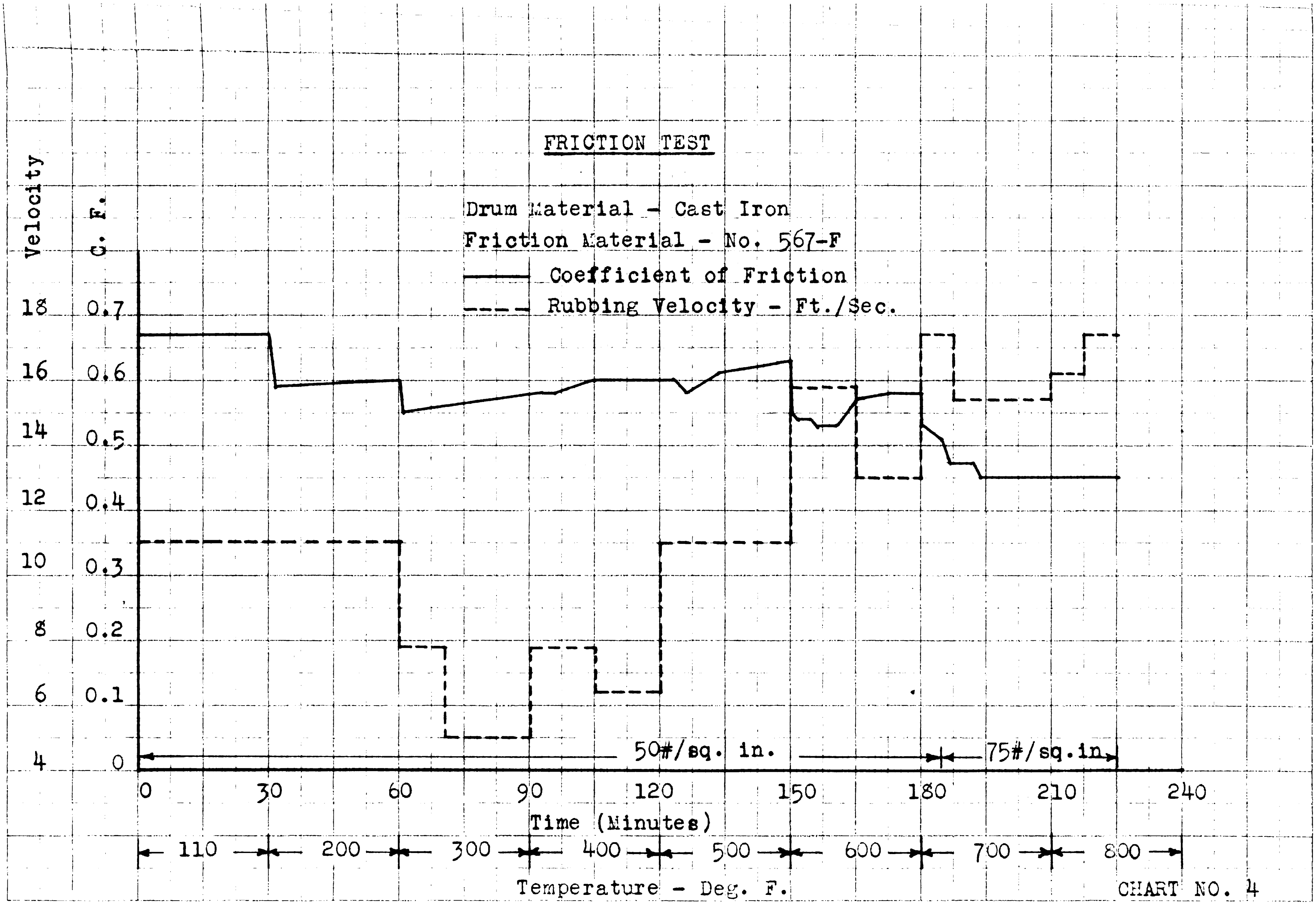

FRICTION TEST
Drum Material - Cast Iron
Friction Material - No. 567-F
Coefficient of Friction
Rubbing Velocity - Ft./Sec.
Velocity
C. F.
18
16
14
12
10
8
6
4
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50#/sq. in.
75#/sq.in.
0
30
60
90
120
150
180
210
240
Time (Minutes)
110
200
300
400
500
600
700
800
Temperature - Deg. F.

CHART NO. 4

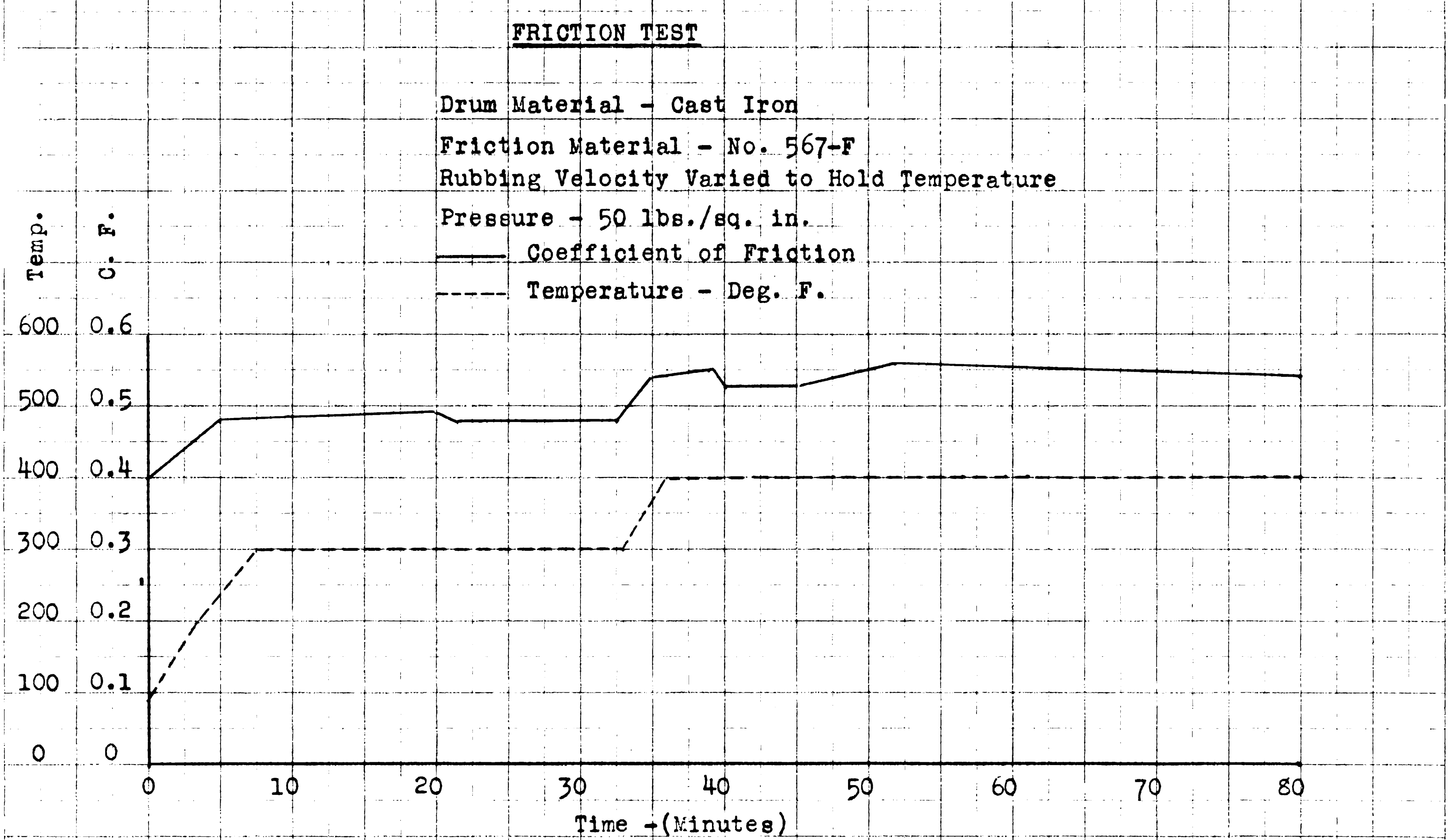

FRICTION TEST
Drum Material - Cast Iron
Friction Material - No. 567-F
Rubbing Velocity Varied to Hold Temperature
Pressure - 50 lbs./sq. in.
Coefficient of Friction
Temperature - Deg. F.
Temp.
C. F.
600
500
400
300
200
100
0
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
Time →(Minutes)

CHART NO. 5

The effects of a wide range of pressure, holding the temperature and rubbing velocity constant, are shown in Chart No. 6.

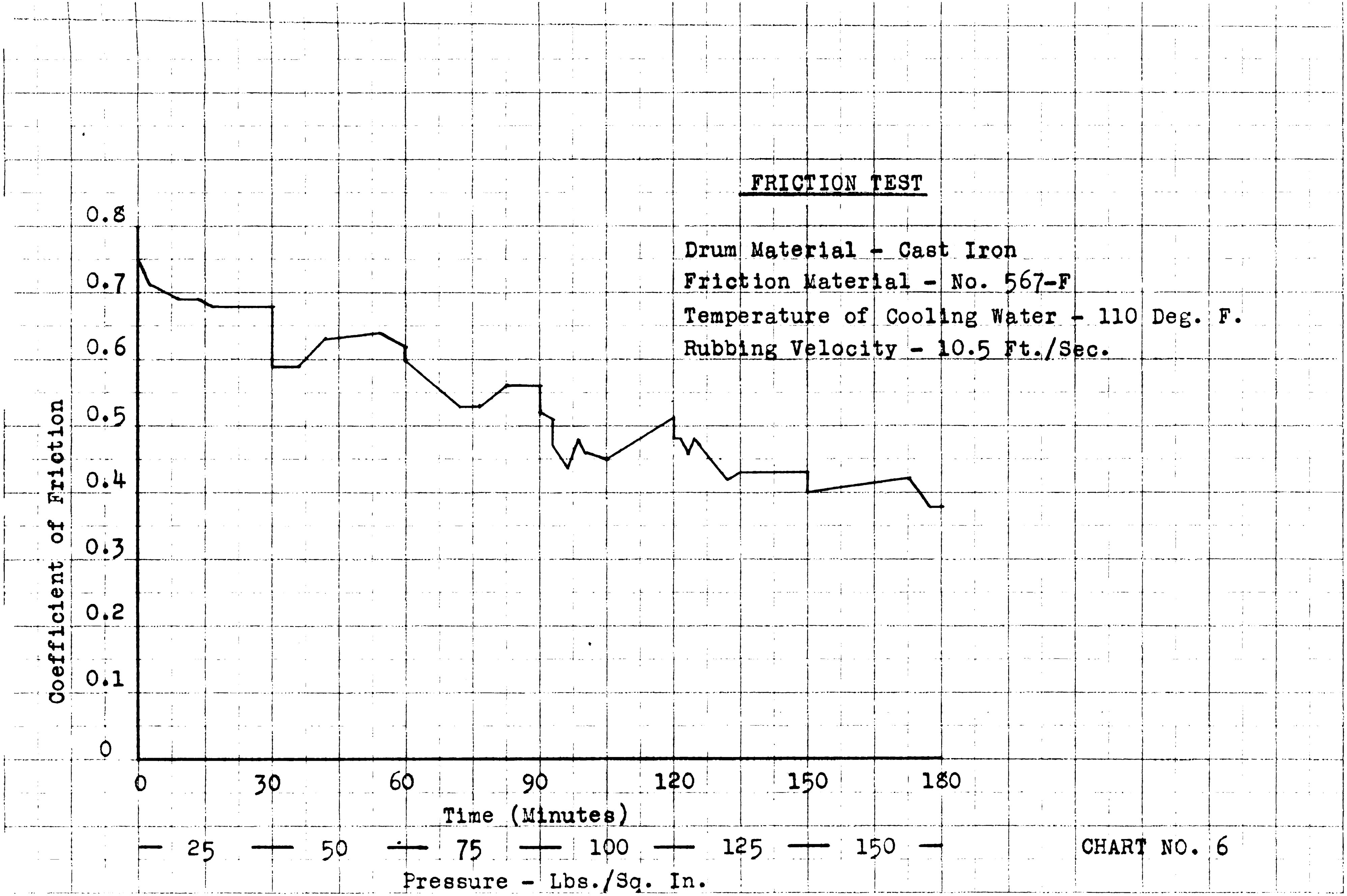
Chart No. 7 shows the effect on friction of temperature changes. In this case, the rubbing velocity and pressure is held constant.

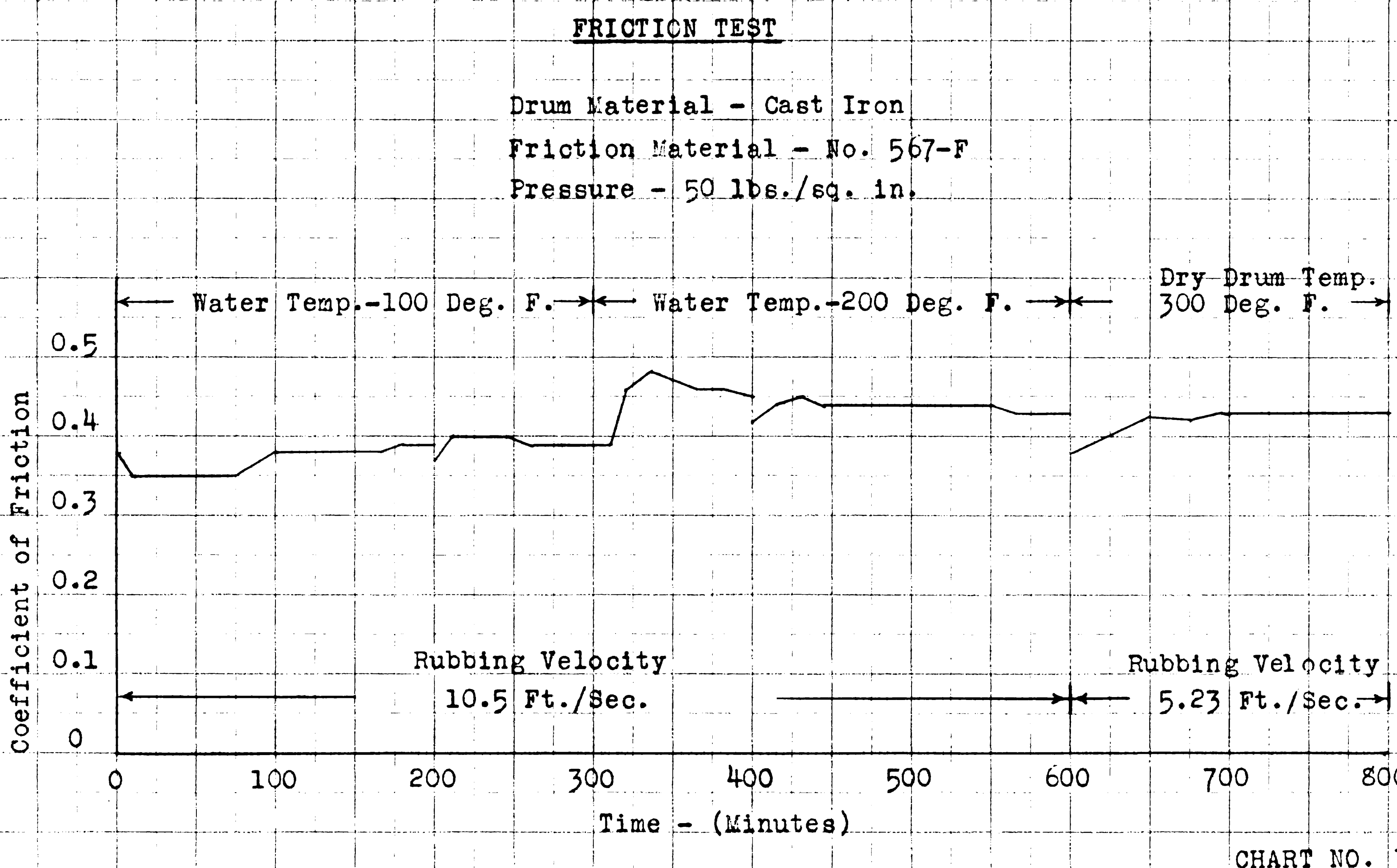
J. B. Derieux (Rubber Chemistry and Technology -- July, 1935) has proven that with rubber compounds, at least, the area of the surface in contact materially affects the friction. He has also proven that with this type of material, in some instances, the value for the coefficient of static friction is less than that of kinetic friction.

In view of the above results, both on drum materials themselves, and on one particular friction material, it is the opinion of the author that the coefficient of friction of a given material depends on the following:

1. Surface condition.
2. Rubbing velocity.
3. Temperature of rubbing surfaces.
4. Normal pressure.
5. Area of contact.

Undoubtedly the value for the coefficient of friction depends on many other characteristics with which the author is unfamiliar. This one fact remains -- that the coefficient of friction of any given material is not as uniform a value as previous theories have held.


FRICTION TEST
Drum Material - Cast Iron
Friction Material - No. 567-F
Temperature of Cooling Water - 110 Deg. F.
Rubbing Velocity - 10.5 Ft./Sec.
Coefficient of Friction
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
30
60
90
120
150
180
Time (Minutes)
— 25 — 50 — 75 — 100 — 125 — 150 —
Pressure - Lbs./Sq. In.
CHART NO. 6


FRICTION TEST
Drum Material - Cast Iron
Friction Material - No. 567-F
Pressure - 50 lbs./sq. in.
Water Temp.-100 Deg. F.
Water Temp.-200 Deg. F.
Dry Drum Temp.
300 Deg. F.
0.5
0.4
0.3
0.2
0.1
0
Coefficient of Friction
Rubbing Velocity
10.5 Ft./Sec.
Rubbing Velocity
5.23 Ft./Sec.
0
100
200
300
400
500
600
700
800
Time - (Minutes)
CHART NO. 7

TESTING OF FRICTION MATERIALS

TESTING OF FRICTION MATERIALS

One of the various types of machines employed in testing friction materials which is widely used is commonly referred to as a "Button Machine". A cross-section of this machine is shown in Fig. 10.

A steel plate having three one-inch square impressions is driven at a desired speed by means of a variable speed motor. Three pieces of lining to be tested are cut to fit these impressions. The head, through which water is allowed to circulate, is then placed in position and the weights are then carried by the head by means of a nut which is tightened on the vertical shaft. The machine is then put into operation and the torque, which tends to rotate the head, is recorded on a recording

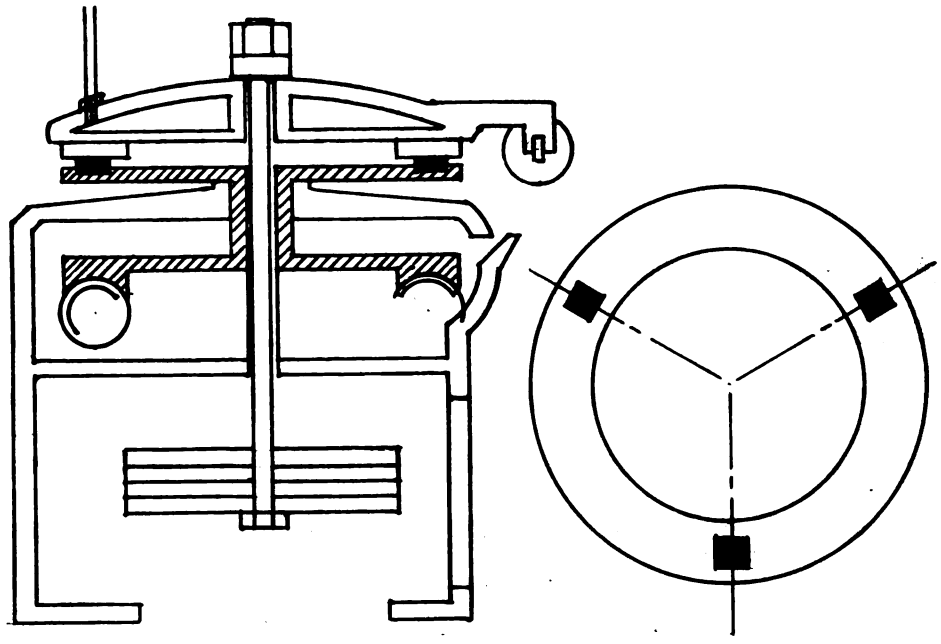


Fig. 10

pressure guage. The coefficient of friction of this lining can then be figured according to the following:

The frictional force acts 6" from the center of the machine, as the lining is 6" from the center, and is measured on the pressure element at 10" from the center. Thus, the frictional force is 10/6 X the force on the pressure element.

After the pressure-load curve is drawn, for every pressure the load on the pressure element is known and the frictional force can easily be found from the above formula.

$$\text{The Coefficient of friction} = \frac{\text{frictional force}}{\text{normal force}}$$

The normal force is three times the unit pressure on the lining if three samples of lining are used.

A curve of coefficient of friction-time can then be drawn. The machine is stopped at 200 minute intervals and the samples are carefully inspected and measured for thickness. From these results, wear figures can be obtained.

The wear units are cubic inches per H.P. hour, so it is necessary to figure the average H.P. for each 200 minute interval. The average coefficient of friction for each 200 minute interval is determined and the corresponding loan (P) on the pressure element is found. This force (P) acts on a 10" radius.

The average total H. P. absorbed =

$$\frac{2 \times 3.1416 \times P \times 10 \times 200}{33000 \times 12} = .031733P$$

The average H. P. per sq. in. = .010577P

The wear in cu. in. per H. P. hour =

$$\frac{\text{loss in thickness} \times 60}{\text{Av. H. P./sq. in.} \times 200}$$

Some results on materials tested by this method are given later in this paper. These machines are generally run at 200 R. P. M., 50 lbs./sq. in., and 110 deg. F. temperature of cooling water. For some purposes they are run at various pressures keeping temperature and speed constant. Again they are run with constant pressure, constant speed, but varying the temperature of the cooling water or not cooling the drum at all, in which case the temperature of the drum is measured by inserting the end of a thermocouple in a hole near the friction surface.

Dynamometers of various types have been and are used throughout the industry. Elaborate machines have been designed which very nearly duplicate actual car performance. Machines of this type are so built that varying energy can be absorbed by a given brake lining in much the same manner as the same material would function on one wheel of a car equipped with four-wheel brakes. These machines are fully automatic in their operation. The minute the brake is applied, all driving forces are disconnected and the brake actually stops a

flywheel that has been running at a given speed with a definite weight. As soon as the flywheel stops, the brake is released and a series of motors pick up the load and bring the flywheel to the given speed again.

ACTUAL TESTS

After all exhaustive laboratory tests have been made, there is but one way to tell definitely what will happen to a certain friction material in actual service - and that is to put it in service such as it will be used for.

In the case of passenger cars, the majority of manufacturers have fleets of test cars. The nature of the tests made on these cars vary with the demands on the lining. The majority of such tests are much more abusive to the lining than ordinary driving conditions. The tests are run to determine the following:

1. What kind of performance will the lining give immediately after installation on a car?
2. How much does this performance vary as the lining is being worn?
3. What effect does water or moisture have on the performance?
4. What effect does dust have on the performance?
5. What effect does excessive abuse have?
6. How does the lining wear?
7. How much noise?
8. How much difference in performance due to different speeds?
9. How much fade during one stop?
10. How much fade during a stop after the lining

has been abused, and does the job stay "square"- that is - does it pull to one side or the other after being abused?

11. After being abused, does the lining glaze and give a hard pedal, or does it recover readily?
12. Does the lining score the brake drums?
13. Does the lining shift on the rivets or come off of the brake shoes?

Different car manufacturers make different demands on linings. It is only natural then that each has a test designed to give the results desired in the least possible time. One company sets up a test schedule as follows:

Make 5 stops from 50 M. P. H. at maximum deceleration, without sliding a tire, at intervals of one mile.
Make 5 stops from 50 M. P. H. at maximum deceleration, without sliding a tire, at 0.25 mile intervals.
Drive 2 miles and repeat above cycle.
This procedure is followed until a certain number of cycles have been run at which time pedal pressure-deceleration "curves" are taken.

Another manufacturer runs a schedule which consists of stops and snubs from 35 M. P. H. These being made at various intervals and at various rates of deceleration, generally completing a test cycle in 14 or 15 miles. Test cars are run on these cycles and deceleration "curves" taken at installation, 2,500, 5,000 and 10,000 miles.

As may be deduced from the above two schedules, one is much more abusive than the other. A given lining may perform with satisfaction on the latter test procedure, but be entirely unsatisfactory if run on the former.

The type of pedal pressure - deceleration curves taken by producers and users of brake lining - vary also. In some instances a robot is used which fastens to the brake pedal. Pressure is applied by means of air moving a piston at a given rate against the pedal. An instrument of this sort automatically records time in seconds, pedal pressure in pounds, deceleration in feet per second, and pedal travel in inches. From this record a curve can be drawn which actually tells what happens, in the way of performance, during one stop. This instrument eliminates any human element which might affect results obtained by other methods of obtaining this information.

Another procedure is by attaching a pressure element to the brake pedal, the pressure gauge being attached to the steering column in plain view of the driver. A Bendix Decelerometer or Tapley Gauge is used to obtain the deceleration values. In this case there is generally an observer who reads the deceleration and records both pedal pressure and deceleration.

In the latter case, immediately after the lining is installed on a car, a curve is taken according to the following procedure:

Make stops one mile apart from 25 M. P. H. starting with a pedal pressure of 20 lbs., and increasing at increments of 5 lbs., until rear tires slide. Record deceleration in ft./sec./sec.

After this curve has been taken, the lining is "burnished in" by making slow speed-slow deceleration stops until at least 90% area of contact is obtained. Another 25 M. P. H. curve is then taken as above, and also the following:

Make stops two miles apart from 50 M. P. H. starting with a pedal pressure of 10 lbs., and increasing at increments of 10 lbs., until rear tires slide. Record deceleration in ft./sec./sec.

Drive 4 miles at 30 M. P. H. to cool the lining and drums.

Make 7 stops from 45 M. P. H. at intervals of 90 seconds, maintaining a deceleration of 15 ft./sec/sec. Record pedal pressure during each stop.

Drive 4 miles at 30 M. P. H. to cool lining and drums.

Make 5 stops from 60 M. P. H. at intervals of 90 seconds, maintaining a deceleration of 15 ft./sec./sec. Record pedal pressure during each stop.

A "set of curves" taken according to the above procedure is shown in Charts No. 8, No. 9 and No. 10.

The curves taken at 25 M. P. H. show the performance

of the lining which might be expected in city traffic. The 50 M. P. H. curve shows an average of what might be expected from a lining when stopping from higher speeds. The 45 and 60 M. P. H. "fade-out" curves give an indication as to what might happen to the performance under severe conditions of operation.

Tests are also made on equipment which is in actual service operation. Large truck and bus companies often install experimental linings on their equipment which is in regular service. Maintenance departments of these fleet operators keep accurate records as to performance of all types. Such organizations must be complimented for their efforts along this line. Not only have they increased the safety of their cargo and passengers, but they have been a big help in the development of friction materials for this type of operation.

DEVELOPMENT OF FRICTION MATERIALS

DEVELOPMENT OF FRICTION MATERIALS

There are undoubtedly hundreds of different friction materials on the market today. In the development of these materials thousands of compounds have been made and tested.

It would be futile to attempt to include all development work which has been done by one company on one type of material, in this paper. However, for purposes of this kind, one particular development will be studied. This lining is of the folded and compressed type.

The base of this material is an open weave plain metallic-asbestos fabric. The waterproofing of this material is a separate development job. It has been found that a satisfactory treatment for this cloth can be made as follows:

Gilsonite	20 lbs.
Parafin	4 lbs.
Gum Damar	12 lbs.
Pure Rubber	2 lbs.
Benzol	52 lbs.
Carbon Tetra-chloride	70 gal.

The rubber is first dissolved in the benzol, the other ingredients are then added and allowed to dissolve. The fabric is then run through this solution and thoroughly dried, before frictioning.

As a starting point in this discussion, consider the following formula:

No. 1631

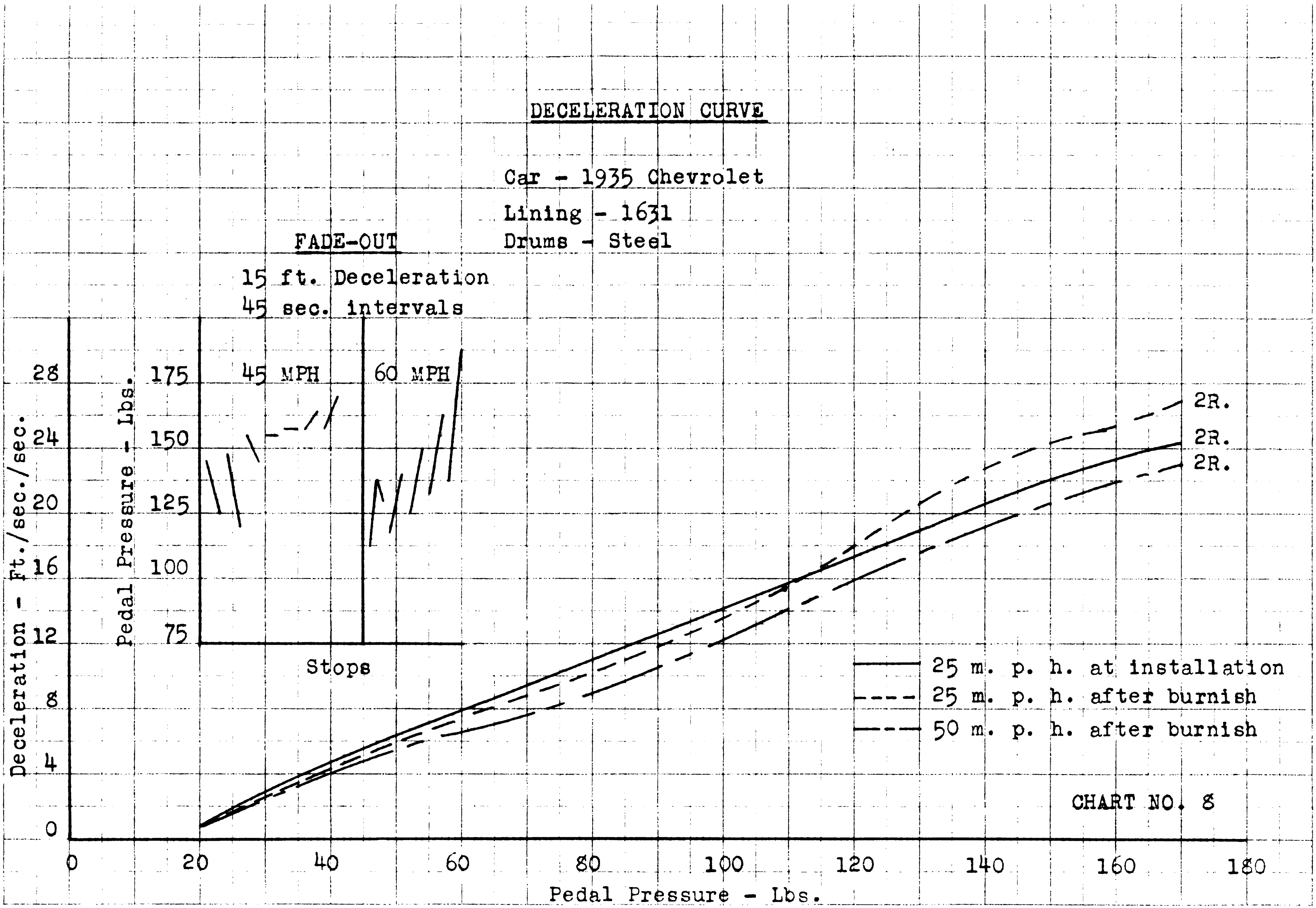
Brown Crepe	30 lbs.
Gas Black	2 lbs.
Graphite	5 lbs.
Asbestine	10 lbs.
Barytes	26 lbs.
Sulfur	15 lbs.
Lime	3 lbs.
Cement	20 lbs.
Petrolatum	7 lbs.
Parafine Oil	2 qts.

This compound mixes readily, is easily processed and the finished lining has a nice appearance. The performance, however, is poor as shown in Chart No. 8. This shows the lining as being too low in coefficient of friction both at installation and after the lining is "seated in". It also shows, on the first three 45 m. p. h. fade-out stops, an increase in friction during a stop. The first concern then is to increase the friction so that a deceleration of approximately 25 ft./sec./sec. may be obtained with a pedal pressure of 100 lbs.

After making several changes in the compound and checking the results on the same car, a material was developed having the following formula:

No. 1678

Brown Crepe	30 lbs.
Gas Black	5 lbs.
Graphite	5 lbs.
Barytes	12 lbs.
Hard Clay	8 lbs.
Mineral Rubber	4 lbs.
Sulfur	15 lbs.
Lime	3 lbs.
Cement	24 lbs.
Petrolatum	6 lbs.
Parafine Oil	2 qts.


DECELERATION CURVE
Car - 1935 Chevrolet
Lining - 1631
Drums - Steel
FADE-OUT
15 ft. Deceleration
45 sec. intervals
45 MPH
60 MPH
Stops
Pedal Pressure - Lbs.
175
150
125
100
75
Deceleration - Ft./sec./sec.
28
24
20
16
12
8
4
0
2R.
2R.
2R.
25 m. p. h. at installation
25 m. p. h. after burnish
50 m. p. h. after burnish
CHART NO. 8
0
20
40
60
80
100
120
140
160
180
Pedal Pressure - Lbs.

This compound presented no processing difficulties, but shows the results given in Chart No. 9. In this case the 25 m. p. h. stops show good rates of deceleration, but the stops from 50 m. p. h. show a hard pedal. The fade-out stops are also undesirable.

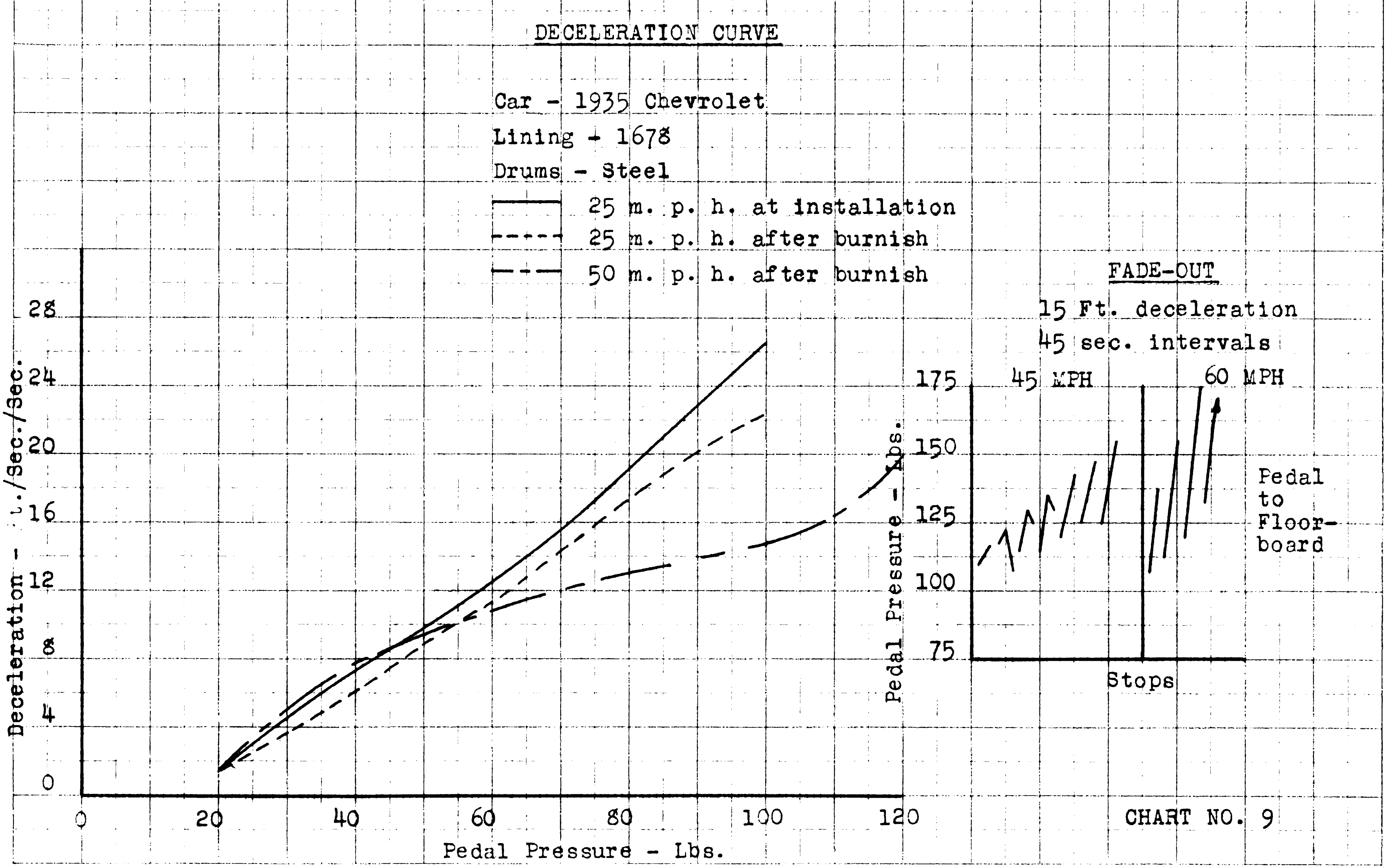
After a considerable number of further tests, a suitable material was developed. This compound has the following formula:

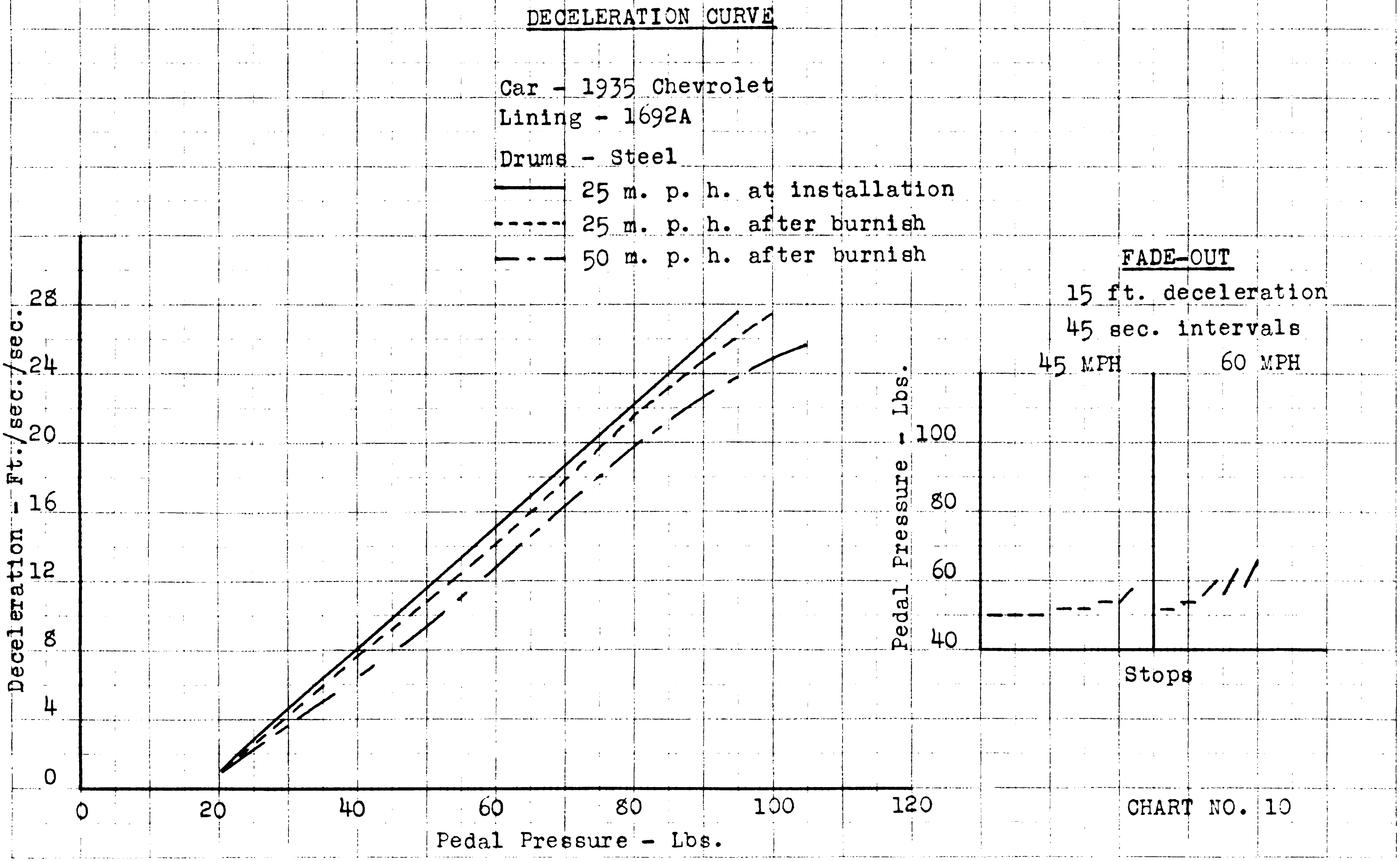
No. 1692-A

Brown Crepe	25 lbs.
Mineral Rubber	5 lbs.
Sulfur	15 lbs.
Barytes	12 lbs.
Hard Clay	10 lbs.
Gas Black	4 lbs.
Lime	2 lbs.
Cement	34 lbs.
Petrolatum	6½ lbs.
Linseed Oil	2 qts.

This compound is easily processed and results in a neat appearing material with good frictional qualities. It shows good wear characteristics, no ill effects when wet and no noise. From the deceleration curves (Chart No. 10), the performance is exceptional and is therefore the end of the search for a material for this one car.

In comparing the three formulas given, it is apparent that radical changes in compounding materials used were not made. On the basis of results obtained on a given car, it is a case where the right proportions of these materials must be used. Should the amount of Hard Clay in formula No. 1692-A be changed, the performance of the lining on the car would be unsatisfactory.


DECELERATION CURVE
Car - 1935 Chevrolet
Lining - 1678
Drums - Steel
25 m. p. h. at installation
25 m. p. h. after burnish
50 m. p. h. after burnish
Deceleration - Ft./Sec./Sec.
0
4
8
12
16
20
24
28
0
20
40
60
80
100
120
Pedal Pressure - Lbs.
FADE-OUT
15 Ft. deceleration
45 sec. intervals
45 MPH
60 MPH
Pedal Pressure - Lbs.
175
150
125
100
75
Stops
Pedal
to
Floor-
board
CHART NO. 9


DECELERATION CURVE
Car - 1935 Chevrolet
Lining - 1692A
Drums - Steel
25 m. p. h. at installation
25 m. p. h. after burnish
50 m. p. h. after burnish
Deceleration - Ft./sec./sec.
0
4
8
12
16
20
24
28
0
20
40
60
80
100
120
Pedal Pressure - Lbs.
FADE-OUT
15 ft. deceleration
45 sec. intervals
45 MPH
60 MPH
Pedal Pressure - Lbs.
40
60
80
100
Stops
CHART NO. 10

At best, development work on materials of this sort is a matter of combining experience in processing together with data obtained on finished linings. A person could undoubtedly check data and develop a piece of material theoretically, which would give ideal results. This material might have to be altered considerably, however, in order to process in a certain way, resulting in a material which might be unsuitable in many respects. Unlike most mechanical problems that can be figured on paper and work if carried out, this type of development work calls for "cut and try" methods. The fact that the actual coefficient of friction is such an indeterminate value is responsible to a large extent for such methods being used in development work on this type of problem.

SUMMARY

SUMMARY

As previously stated, this paper is merely a small collection of information pertinent to the manufacturer of friction materials.

After the manufacturer puts a piece of lining on the market for a certain car, other problems arise for which he is held responsible. For example -- when a person buys a new car or has the motor overhauled, he carefully "breaks it in" so as to secure smoothness of operation and long life with a minimum of expense. He feels that the motor is the most important part of the machine. In the other case -- he wears out a set of brake lining. Having had the lining replaced, he proceeds to use the brakes harder than ever. He feels that he can stop the car from any speed regardless of whether the lining is seated in or not. As a result, possibly a brake lining failure occurs, in which case the manufacturer is at fault. Had this new lining been broken in as carefully as one would break in a new set of connecting rod bearings, this failure, in all probability, would not have occured. After all, the motor is essential and its repair is of importance. At the same time this motor, on which much work has been done, generates the power to propel the car, and so must the lining be able to dissipate the energy stored up -- in the form of heat. In a large majority of cases, it is more necessary to be

able to stop a car than it is to have it run smoothly and at excessive rates of speed. Is it not, therefore, as essential that the operator of an automobile be as particular about the condition of the brakes as about the motor?

The industry as a whole must make great strides in the development of more perfect brake linings, so must the car operator become more "brake-conscious". The culmination of these efforts together with the efforts of car manufacturers and brake designers, will make for more safety.