Dec. 28, 1954 T. G. LEWIS 2,697,900

LAPPING METHOD

Filed May 12, 1953

Fig. 1.

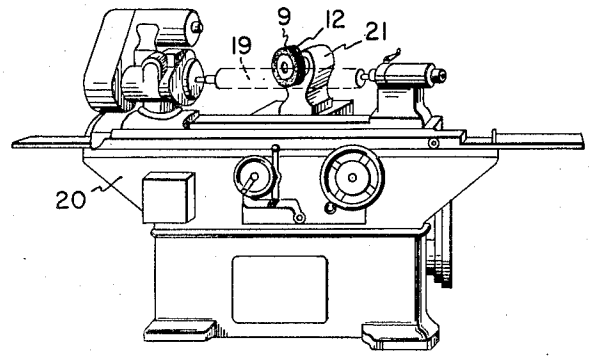


Fig. 2.

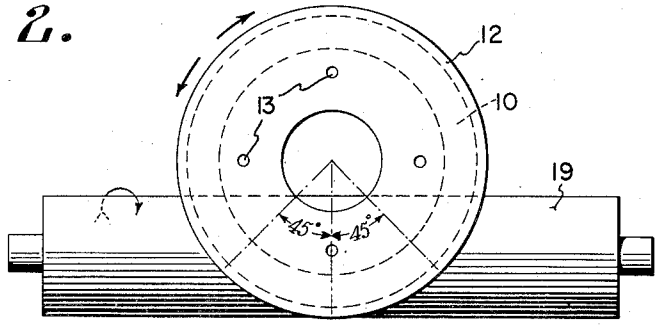


Fig. 4.

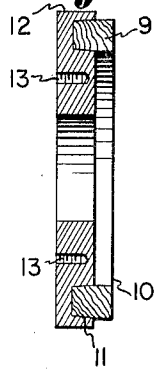
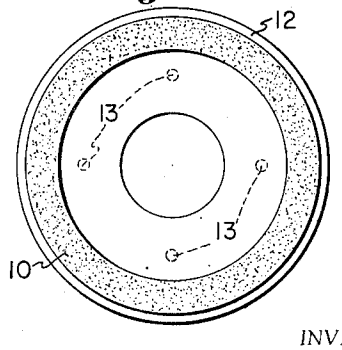


Fig 3.



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2,697,900

Patented Dec. 28, 1954

2,697,900

LAPPING METHOD

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Application May 12, 1953, Serial No. 354,583

6 Claims. (Cl. 51—289)

This invention relates to an improved method for lapping metallic articles, and particularly to a method for the lapping of articles fabricated from non-homogeneous or inclusion-bearing metal alloys and metals, or metallic structures displaying non-homogeneous characteristics to abrasion, to develop thereon an exceedingly high quality surface finish.

Metal alloys and some metals, to varying degrees, are non-homogeneous to abrasion and therefore it is difficult to lap these materials at a substantially uniform rate necessary to develop high quality surface finishes with good dimentional control. Typical examples of such materials are the high tungsten, vanadium and chromium content alloy steels, wherein relatively rich carbide concentrations exist at the grain boundaries or at other points. These carbides are usually much harder than the metal of the grain interiors and, in the case of vanadium carbide, at least, may be of a greater hardness than aluminum oxide abrasive itself. An even more serious problem from the standpoint of lapping is that of the impurity inclusions which are found in all commercial grades of metal alloys. These inclusions may comprise small amounts of silicates, sulfides or other substances, or refractory particles picked up from the smelting furnace, which may be either harder or softer than the primary metal constituent and thus possess a different abrading characteristics. When metal alloys are lapped by the conventional methods now known to the art, inclusions invariably tear away from the surrounding metal, leaving pits behind which reduce the quality of the finish. Usually the dislodged inclusions join the abrasive and are forced against the work surface one or more times during later passes of the lapping tool, thus producing scratches which additionally mar the finish. Yet another cause of pitting is believed to be point welding, which may occur between the tool and the work under the high temperatures which exist within the small area of contact. The breaking of point welds under the relative movement of the lap and the work tears small pieces of metal away, with resultant pitting, and the free metal particles intermingle with the abrasive and deface the work surface upon being carried into the contact area during subsequent operation.

U. S. Patent 2,612,736, property of the same assignee, taught a process and a lapping device for the attainment in materials of the type hereinabove mentioned of lapped surfaces having qualities of the order of 1–2 microinches root-mean-square, and the instant invention constitutes an improvement over the patented process by which it is possible to obtain appreciably higher surface qualities. High quality surface finishes are essential to certain uses of the materials in polymeric material film casting wheels, polishing rolls for coated fabrics and the like. Pure metals, such as electroplated chromium, for example, are generally free of inclusions but are apparently still non-homogeneous to abrasion, since it is very difficult to secure a high quality finish thereon while still retaining good dimensional control.

I have now found that it is possible to lap metal alloys and also metals to finishes having qualities substantially better than 1.0 microinch with high dimensional accuracy by forcing a diamond dust abrasive against the work with a balsa wood lap in the presence of a small amount of wax while maintaining a predetermined pressure of contact and a high relative speed of translation of the surfaces, whereby all areas are abraded at substantially the same rate and inclusions are not torn from the matrix metal. A primary object of this invention, therefore, comprises providing a method for the lapping of articles fabricated from metal alloys or metals to exceedingly high quality finishes. Other objects include the provision of a method of lapping articles fabricated from metal alloys or metals which is rapid and economical, and which is subject to high dimensional control, so that the finished articles conform to very precise size standards. The manner in which these and other objects of this invention are attained will become apparent from the detailed description of this specification and the following drawings in which:

Fig. 1 is a perspective view of an apparatus adapted to lap a work-piece of cylindrical shape according to this invention, the outline of the work in set up position being shown by broken line representation;

Fig. 2 is a rear elevational view showing a preferred disposition of lap in relationship to a work-piece of cylindrical shape;

Fig. 3 is a front elevation of one embodiment of lap according to this invention; and

Fig. 4 is a sectional view taken along the vertical axis of the lap shown in Fig. 3.

Lapping according to this invention may be conducted by applying the diamond abrasive and the wax separately to the balsa wood lap prior to commencement of the lapping operation; however, it is preferred to make up a wax stick incorporating the diamond substantially uniformly distributed therein and apply both the diamond and the wax to the lap simultaneously for reasons of convenience in the application and economy in diamond consumption through the elimination of losses which result when the free abrasive is dusted on.

The lap of this invention may conveniently comprise a single piece of balsa wood cut transverse the trunk, the ends of the fibers presented constituting a more uniform surface than is obtained when the wood is cut with the grain. Large laps can be built up by assembling a multiplicity of pieces cut across the grain into the lap configuration desired and holding the pieces rigidly together by a suitable device such as that hereinafter described with reference to Figs. 3 and 4, so that a substantially continuous surface is provided for forcing the abrasive against the work. Since it is necessary to maintain high relative surface speeds during lapping, it is preferred to employ laps of annular shape in the practice of my method, for the reason that this configuration is stable and strong enough to withstand very high rotational speeds.

In Figs. 3 and 4, the balsa wood lap **9** comprises a unitary annulus cut tranverse a block of wood, so that the ends of the wood fibers make up the working face **10** which contacts the work during lapping. Since the lap is subjected to relatively high stresses during use, it is desirable to provide support by mounting the lap tightly within the annular recess **11** of the circular metal holder **12** with a light drive fit and to cement securely the surfaces of the lap in contact with recess **11** to holder **12** with a suitable high strength commercially available cement. The rear face of holder **12** is provided with tapped holes **13** for the reception of bolts for attachment of the lap to the flange of a powered rotating spindle. The lap shown in Figs. 3 and 4 is adapted to the lapping of cylindrical work pieces and the working face **10** is therefore machined to a plane, smooth surface throughout. Where it is desired to lap plane surfaces, it is preferred to machine the outer edge of face **10** on a bevel and maintain holder **12** during operation at an inclination such that the beveled edge is parallel to the work surface, the work and tool being indexed laterally relative to one another to the extent necessary to lap by successive traverses the desired surface area, whereupon substantially equal eras of the lap contact the work as in the case of cylindrical work when the same loading pressures are used.

Lapping according to this invention can be carried out with conventional machine shop equipment of the type shown in Fig. 1, wherein the cylindrical work-piece **19**, in broken line representation, is set up between the centers and turned by a standard grinding machine **20**, such as a Brown & Sharpe, Model No. 4, Universal Grinding Machine. The lap, of the design shown in Figs. 3 and 4, is powered by a heavy duty motorized spindle **21**, such

as a Pope Machinery Corporation Series P–2500 design, which is substituted for the conventional grinding wheel of the grinding machine but is made to traverse the lap lengthwise of the work-piece **19** by the operation of grinding machine **20** in the usual manner. The in-feed of the lap against the work is conveniently gauged by maintaining the horsepower input to the spindle motor at a sufficient level for each of the sizes of abrasive used to maintain high quality lapping at a satisfactory rate. A power demand meter, not shown, of the type represented by the Weston Model 639 Industrial Analyzer is connected in circuit with the motor of spindle **21** to provide the operator with an indication of the existing loading during operation. It will be understood that the particular apparatus hereinabove described constitutes but one arrangement of many which can be employed for the purpose, and that numerous other arrangements known to those skilled in the art may be used, depending on the size and shape of the work to be lapped and the practicable speeds at which the work or the lap can be turned.

In the lapping of cylindrical work, good results are obtained when the surface of the lap is disposed substantially tangent to the surface of the work, as indicated in Figs. 1 and 2. The center line of the lap-powering spindle may be coplanar with the longitudinal axis of the work or may be disposed thereabove; however, it is preferred to locate the lap as shown in Fig. 2, wherein the angle between the line of contact of the lap with the work and the vertical is approximately 45 degs. With this disposition, the right-hand area of contact of the lap passes the work at an inclination of 45 degs. to the right while the left-hand area of contact passes the work at an inclination of 45 degs. to the left, thus providing a broken pattern which is desirable in lapping regardless of the particular method involved. Equally good results are obtained when the lap is turned in either a clockwise or counter-clockwise direction as viewed in Fig. 2.

It is essential to the purposes of this invention to employ a wax in conjunction with the diamond dust abrasive and balsa wood lap. The exact functioning of the balsa wood and wax during the lapping operation is not understood with certainty; however it appears that the peculiar nature of the balsa wood and of the thin layer of wax interposed between the lap face and the work combine to afford an optimum compromise between cutting rate and differential heat generation to achieve the very high surface qualities which are obtained. It is believed that the balsa wood has a softness such that it will not hold the diamond dust against the work with sufficient force to cause scratches, while still possessing enough retentivity for the diamond to effect a certain amount of lapping. I have found that there is a limiting softness for balsa wood which renders it useless for the purposes contemplated, which can be determined by testing the wood in a conventional Rockwell hardness tester with a ⅝″ diameter tool steel ball under a loading of 60 kgs. The test is conducted on the wood in an end grain direction and measurement of the diameter of the crater left by the steel ball on cessation of penetration, which usually occurs within about 20 secs., affords a convenient index of the hardness. Indentations of diameters in excess of about 9/32″ are an indication that the wood is too soft for use as a lap. Insofar as my experiments have revealed there is apparently no upper limit on the hardness of the balsa which affects lapping action.

The wax is believed to exist as a highly viscous suspension medium for the diamond under the localized temperature developed during the lapping operation, thereby restricting the movement of the diamond particles to the precise extent necessary to effect lapping when backed up by the balsa wood block. This theory is offered as the most logical explanation for the phenomenon observed known to me; however, lapping action is very complex in its nature and perhaps other equally logical theories can be postulated. By differential heat generation I mean the heat generated within local areas being lapped under the action of the lapping tool, such heat when excessive causing unequal expansion of the work-piece which finally results in eccentric rotation of the work, or "whipping," sufficiently serious to cause loss of dimensional control. I have found that the hard waxes, such as beeswax and carnauba, are particularly effective in reducing differential heat generation, particularly as regards work-pieces having length/diameter ratios below about 5.0. Where the configuration of the work-piece is such that this general limit is exceeded, whipping evidencing aggravated differential heat generation occurs in spite of the wax and, once this stage is reached, the operator has no option but must discontinue lapping until the work is cooled, after which operations can be continued.

Liquid waxes appear to be of some utility in eliminating heating but their efficiency appears to be considerably lower than the solid waxes. While beeswax and carnauba wax individually appear to reduce differential heat generation, I have found that a blend of these two waxes in the proportions of about 40–60% carnauba wax to 60–40% beeswax is particularly effective and I prefer to use this mixture for the preparation of my wax sticks. The sticks are prepared by melting the wax and stirring in the particular grit size of diamond dust abrasive which it is desired to employ until a uniform distribution of the diamond is obtained, whereupon the wax-diamond mixture is poured into cylindrical molds and chilled to solidity before diamond stratification can occur. A typical stick may comprise about 10 gms. of carnauba wax, about 10 gms. of beeswax and 10 carats of diamond dust, the lapping hereinafter reported being conducted with three separate sticks made up with 3200, 6400 and 13,500 grit size diamond dust, respectively. The wax is preferably used sparingly for the reason that an excess contributes to heat generation, it being only necessary to maintain a very thin film over the surface of the work, which can readily be determined visually by the dull luster imparted when sufficient wax is applied. In a typical case about one gram of wax-diamond mixture of the composition hereinabove described, made up with 6400 grit size diamond, was sufficient for the lapping of a 218 sq. in. surface cylindrical metal work-piece in the course of 20 passes of the lap past the work.

In this instance the work-piece was fabricated from Stellite No. 1 of the analysis hereinafter detailed and was cylindrical in form with a diameter of about 6″ and a length of about 12″. The lap comprised a 1″ thick segmental balsa wood ring of 6⅞″ inside diameter and 8⅞″ outside diameter, thus providing a working face of 1″ width. The work-piece was turned in the grinding machine at a speed of 40 R. P. M., and the lap was turned at a speed such that the relative velocity between the work and the lap was about 8000 ft./min. A power input of 3.0 H. P. was preserved during the operation, and the lap was traversed across the work at a rate of 1″ lateral travel per revolution of the work-piece, a single pass requiring about 18 secs. After 10 passes, or 3.0 mins., lapping was discontinued and the work was allowed to air cool for an interval of about 20 mins. before making the final 10 passes. The quality of the work to begin with was about 1.0 microinch R. M. S., while the final quality was an estimated 0.6–0.7 microinch. It will be understood that the precise ratings of finishes of such high quality as those with which this invention are concerned are approximate, due to the fact that techniques have not yet been developed which permit absolutely accurate measurements within this range; however, all finish ratings herein reported were obtained with a highly sensitive multiple beam interferometer, this instrument being considered the most accurate available.

Observations indicate that effective lapping occurs at work-piece temperatures ranging from room temperature to about 400° F. or even higher, so long as differential heat generation does not cause whipping detrimental to the requirements of dimensional control. The thin wax film on the work blackens somewhat during operation and this visually perceptible color change affords a convenient indication that lapping action is being obtained. In general, I have found that it is desirable with most work to maintain an upper limit of surface temperature of between about 120–140° F. where high dimensional accuracy is of critical importance. The pressure loading which it is desirable to preserve is not particularly critical, a loading in approximately direct proportion to the diameter of cylindrical work-pieces giving good results for the same materials of fabrication, all other conditions remaining the same. In the practice of my method it is necessary to maintain a relative speed of translation between the contacting surfaces of the lap and the work of the order of about 5000 ft./min., and preferably 7500–10,000 ft./min. At speeds in the lower end of the range, i. e., around 5000 ft./min., some materials display the defect known in the lapping art as "orange peel," which is effectively prevented if higher relative speeds are preserved. At the other end

of the range good lapping occurs at speeds up to and higher than about 15,000 ft./min.; however, heat generation becomes aggravated at these very high speeds without accompanying advantages and also the low inherent strength of the balsa wood lap makes it inadvisable to operate at this extreme.

The lapping of surfaces from their original state to the final finish is a progressive operation, involving the use of a series of diamond dust sizes ranging from relatively coarse at the beginning through successively finer sizes to the end. The faces of the balsa wood laps employed during each lapping step becomes charged locally with diamond dust, and it will be understood that a lap which has been previously used with a coarser size of diamond dust should not be employed to attain a higher quality with a finer size unless the charged region is first removed and a fresh surface exposed to the work. This can be accomplished conveniently by cutting away the face of the lap to a depth of about 1/32" in a lathe with a diamond point tool. In addition, balsa wood laps wear unevenly in the course of use, which is evidenced by a periodic "bumping" sound during operation, which becomes more noticeable as high spots develop. It is therefore preferred to dress the lap to restore an even contacting surface before bumping becomes serious enough to cause blemishes in the work, and this can be accomplished by trimming the face of the lap to a depth of 0.005"–0.010" with a diamond point tool at interval of about one hour's operation. Upon completion of lapping with a given size of abrasive, the surface of the work is cleaned by flushing or gently washing with a solvent, such as carbon tetrachloride, followed by a final wash with water containing a detergent. Soft absorbent paper or cotton are preferably used to dry the lapped surface and to remove any remaining traces of abrasive, after which lapping is started with the next finer size of abrasive.

Lapping according to this invention has proved particularly effective for the high quality finishing of the relatively hard alloy steels, of which the following are representative, and the loadings for these materials, typified by the 440–A example hereinafter reported in detail, constitute a guide which, supplemented by observations in the course of lapping other materials, will enable others to practice my method:

Analysis, in percent

Material	C	Mn	P	S	Si	Cr	Ni	Cu	Fe	Surface, Rockwell C Hardness
Armco Iron R1104	0.06	0.55	0.013	0.012	0.39	16.34	4.00	3.90	Balance	39
AISI 440–A	0.60	1.0	------	------	1.0	15.0	1.25	------	Balance	55

	C	Mn	P	S	Si	Cr	Mo	V	Fe	
Latrobe Electric Steel Co.'s BR–4	2.4	0.40	------	------	0.40	12.8	1.1	4.0	Balance	65

	Cr	W	Balance	
Stellite No. 1	28–34	11–15	Co	55

	Ni	Co	Cr	Mo	B	Mn	C	All Others	
X-Alloy 306	40	30	15	8	2.5	1.0	0.5–1.0	2.5–3.0	58

A 4" dia. centrifugally cast shell of 12" length and ½" wall thickness fabricated from commercial quality 440–A steel of the anlysis tabulated, having a measured Rockwell C hardness of 59, was mounted on a mandrel and lapped according to this invention in the following manner, using the apparatus shown in Figs. 1–4. The lap comprised a 1" thick segmental balsa wood ring of 6⅞" inside diameter and 8⅞" outside diameter, thus providing a working face of 1" width.

The shell was first reduced to a diameter 0.002–0.003" above the desired finished diameter, using conventional powered grinding equipment. The finish after grinding was about 16 microinches R. M. S. The shell was then lapped with a lignum vitae wood lap in accordance with the method of U. S. P. 2,612,736 in three separate steps of 1 hour duration each, employing 800, 1600 and 3200 grit sizes of diamond dust together with olive oil in the order recited until a final finish of 1–2 microinch R. M. S. quality was attained. The shell was then finished with a balsa wood lap and diamond-wax applications in three separate steps in the following chronological order, a loading of 2.0 H. P. being preserved throughout, except during final operation under the last step of the sequence. To facilitate the maintenance of temperature control during lapping, the mandrel supporting the shell was drilled at two points adjacent the ends of the shell and provided with rotary joints for the introduction and removal of cooling water, which was continuously circulated through the interior of the shell during the complete lapping cycle. The surface temperature of the shell was maintained between the limits of 120–160° F. for all three lapping steps by suitably regulating the flow of cooling water through the shell. In all cases diamond-loaded wax sticks made up in the proportions of 10 gms. carnauba wax, 10 gms. beeswax and 10 carats diamond dust of each of the three grit sizes were employed for the application of abrasive to the balsa wood lap. The shell was turned at a speed of 55 R. P. M., and the lap was traversed axially at a rate of 1" lateral travel per revolution. A relative speed of work to lap of about 8000 feet per minute was preserved during operation, the lap being turned at a speed of about 3625 R. P. M.

Step 1

Lapping was initiated with a 3200 grit size stick, the abrasive being applied to the lap by several short light pressure strokes by the operator and the lap being traversed lengthwise of the shell for one or more preliminary passes to determine visually if a continuous layer of the wax was laid down. For the size of work specified an application of about 1.0 gm. of wax-diamond was sufficient for good results, until redressing became necessary when, of course, it was necessary to add new wax-diamond to the lap to replace that which was removed. The first step of wax-diamond lapping required 4.0 hrs. of lapping time, the wheel being redressed three times at about equal intervals during this period whereupon a final surface quality of about 0.7 to 1.0 microinch R. M. S. was obtained. The lap was then thoroughly washed with carbon tetrachloride and the outer face was cut away with a diamond point tool to a depth of about 1/32" to provide a fresh surface for Step 2.

Step 2

This step was conducted with a 6400 grit size stick in essentially the same manner as Step 1, except that the duration of operation was 1.0 hr. during which it was found that no redressing of the lap was necessary. The final surface obtained was of the order of 0.4–0.7 microinch R. M. S. The lap was cleaned and refaced as described for Step 1 prior to commencing Step 3.

Step 3

This step was conducted with a 13,500 grit size stick in essentially the same manner as for Steps 1 and 2, except that the duration was limited to 1.0 hr. and during

the last 10 passes of the lap past the work the loading was reduced to about 1.0 H. P., which seemed to yield a somewhat improved surface over that secured by maintaining the 2.0 H. P. loading to the very end of operation, as was determined by comparison with the results achieved in an independent test on the same composition material where the latter higher pressure loading was employed throughout. A final surface quality of the order of 0.1 to 0.3 microinch R. M. S. was obtained at the end of this step with retention of good dimensional control.

From the foregoing it will be understood that my invention may be modified in numerous ways obvious to those skilled in the art without departing from the essential spirit, wherefor it is intended to be limited only by the scope of the following claims.

What is claimed is:

1. A method for the lapping of an article fabricated from a metal alloy or metal comprising forcing a diamond dust abrasive against said article in the presence of a wax with a balsa wood lap, said lap having a hardness greater than that evidenced by a diameter of indentation measuring in excess of about 9/32" for a 5/8" diam. tool steel ball pressed against said balsa wood with a loading of 60 kgs. in an end grain direction, while maintaining a relative speed of translation between the surfaces of said lap and said article above about 5000 ft./min. and a loading pressure sufficient to blacken said wax in the area of contact of said lap with said article.

2. A method for the lapping of an article fabricated from a metal alloy or metal in two separate contactings of the lap with said article wherein the direction of translation of the lap with respect to the surface of said article during one of said contactings is maintained substantially normal to the direction of translation of the lap with respect to the surface of said article during the other of said contactings, each of said contactings comprising forcing a diamond dust abrasive against said article in the presence of a wax with a balsa wood lap, said lap having a hardness greater than that evidenced by a diameter of indentation measuring in excess of about 9/32" for a 5/8" diam. tool steel ball pressed against said balsa wood with a loading of 60 kgs. in an end grain direction, while maintaining a relative speed of translation between the surfaces of said lap and said article above about 5000 ft./min. and a loading pressure sufficient to blacken said wax in the area of contact of said lap with said article.

3. A method for the lapping of an article fabricated from a metal alloy or metal comprising forcing a diamond dust abrasive distributed in a wax against said article with a balsa wood lap, said lap having a hardness greater than that evidenced by a diameter of indentation measuring in excess of about 9/32" for a 5/8" diam. tool steel ball pressed against said balsa wood with a loading of 60 kgs. in an end grain direction, while maintaining a relative speed of translation between the surfaces of said lap and said article above about 5000 ft./min. and a loading pressure sufficient to blacken said wax in the area of contact of said lap with said article.

4. A method according to claim 3 wherein said wax comprises a blend of carnauba wax with beeswax.

5. A method according to claim 3 wherein said wax comprises a blend of about 40–60% carnauba wax to 60–40% beeswax.

6. A method for the lapping of an article fabricated from a metal alloy or metal in a succession of steps employing progressively finer graded particle sizes of diamond dust abrasive comprising forcing each of said sizes in turn against said article in the presence of a wax with a fresh balsa wood lap, said lap having a hardness greater than that evidenced by a diameter of indentation measuring in excess of about 9/32" for a 5/8" diam. tool steel ball pressed against said balsa wood with a loading of 60 kgs. in an end grain direction, while maintaining a relative speed of translation between the surfaces of said lap and said article above about 5000 ft./min. and a loading pressure sufficient to blacken said wax in the area of contact of said lap with said article, and cleaning the surface of said article after each said step before beginning the next succeeding step.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
2,612,736	Lewis	Oct. 7, 1952