SYMPOSIUM ON DIAMONDS

(1) INTRODUCTORY STATEMENT

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At the 1941 meeting of the Mineralogical Society of America held in Boston, the first symposium on diamonds was conducted. It was arranged because the greatly increased use of diamonds in industry, due largely to the war effort, prompted manufacturers and users of industrial diamonds to seek counsel and advice of mineralogists, who for the most part had given little attention to the industrial application of the mineral.

The participants in the symposium presented a large body of information concerning the production and the many uses of the diamond as a gem and in industry. The papers were published in the March 1942 issue of the *American Mineralogist** and attracted wide interest as is evidenced by the insistent and very gratifying demand for reprints in this country and abroad.

Pursuant to the desire expressed by those in attendance at the symposium, it was planned to arrange a similar program for the 1942 meeting of the Society to be held in Ottawa. Transportation and other difficulties, because of the war situation, made it necessary to cancel the annual meeting of the Society and consequently the symposium could not be held. It seemed wise, nevertheless, to secure brief statements concerning the changes and progress which had been made during the past year in production, the cutting of gem diamonds, diamond dies in the United States, diamond-set tools, and bonded diamond wheels from those who discussed these phases last year.

Because of the related character of the papers it has been deemed desirable that they should again be published together.

(2) DIAMOND PRODUCTION

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The world's diamond production, from 1940 to 1941, fell from over 14,250,000 carats to slightly under 9,350,000, a decrease of about 34 per cent. The major factor in the decrease was a fall of almost 4,800,000 carats in the Belgian Congo production, but most other districts showed decreases—the exceptions being the Gold Coast, Sierra Leone and South-West Africa. In 1942 the production presumably will approach that of 1941. Thereafter, if the war continues, a marked decline in production

* Pages 162–191.

may be expected, due to staff shortages and difficulties both in obtaining needed supplies and in shipping them to the remote regions in which the mines are situated. A number of the producing companies' engineers have signed up with the armed forces and replacements are impossible.

In 1941, industrial stones, mainly crushing bort, comprised 78 per cent of the production; in 1942, a slightly greater percentage, as the producing companies are pushing the exploitation of those mines which furnish a high percentage of industrial stones and relatively few gem stones. If the war continues, the relative percentage of industrials will continue to increase.

In 1941, by weight, Equatorial Africa (Congo, Gold Coast, Sierra Leone and Angola) accounted for 94 per cent of the production; South Africa and South-West Africa for two per cent; South America (Brazil, Venezuela and British Guiana), four per cent. The attempt by the Board of Economic Warfare to increase the production of other minerals in Minas Geraes, drawing their labor from the same pool, will presumably in 1942 result in a somewhat decreased diamond production in Brazil. As the African pipe mines were shut down (and are not likely to re-open for the duration), all diamonds are now derived from alluvial mines. Of the production of the African continent, two per cent came from gravels derived from Cretaceous pipes and 98 per cent from gravels derived from deposits of pre-Cambrian age. In 1941 the British Empire produced 20 per cent by weight (14.2 per cent in 1940) and 31 per cent by value (37.1 per cent in 1940) of that year's production. A single mine, Beceka, in the Belgian Congo, an extraordinary deposit both from its high diamond content and the size of its reserves, produced 58 per cent of the 1941 production.

Due to the tremendous increase in the use of the diamond in industry, it is fortunate that there are available to the United Nations considerable stocks above ground, for a few months hence demand will exceed current production. These stocks consist of relatively large surpluses in the hands of the Diamond Corporation and those in the hands of the producers not as yet delivered to the Corporation and, in addition, a healthy stock-pile here in America, divided in ownership between the government and industry. The United Nations are not short of diamonds, but certain finer grades have been scarce for four years, a potent reason to keep the mines in operation, since the finer industrial stones can only be produced as a small by-product of the run-of-the-mine output. Users must school themselves to employ poorer grades than formerly, and practice will show that these "inferior grades" will fulfill their mission admirably. It must be balm to Leon Henderson's heart that since the war began the price of industrial stones has been stabilized, thanks to the patriotism of

Sir Ernest Oppenheimer and the other directors of the Diamond Corporation, and of those of the producers.

The United Nations have, from the beginning of the war, had at their command the product of practically all the diamond mines of the world. A few months ago the mines of French Guinea fell into their lap and now Axis powers control only the Borneo mines, which account, in a normal year, for perhaps two one-hundredths of one per cent of the world's production. We understand that Germany is already woefully short of industrial diamonds and she is already using gem stones industrially. Japan also is in need of more diamonds, but since her citizens have only in relatively recent years appreciated the diamond, she has not many gem stones to fall back on. The shortage of industrial stones in the camp of the Axis powers can scarcely stop their war production; it may, however, slow it down appreciably.

We have previously emphasized that, of all the critical minerals and metals, the use of the diamond industrially is one of the most rapid in growth. This is particularly true of crushing bort. Many new companies have, in the past year, commenced to manufacture cutting wheels and other articles of which the cutting agent is diamond-dust bonded in a powdered metal or with a plastic. In consequence, the demand for crushing bort has doubled or quadrupled in the past year. The use of diamond dies and diamond-set tools has also greatly increased; that of diamonds in drilling has, on the other hand, fallen off, as prospecting, particularly in Canada, has slumped markedly since the war began. This loss to the bort market has been offset in part by the larger use of diamonds in blast-hole drilling. Nineteen forty-one saw the transfer of the diamond-die industry from France to the United States. Even after the war is over we will find industry demanding working diamonds in quantity.

War has, again, restricted the sale of "rough" suitable for gems, but so large have been the sales of industrial diamonds in 1942 that the Diamond Corporation will sell, in the year, more stones than in any year since 1937. The United States, however, continued to buy many gem diamonds, but due to the inroads on large fortunes, most sales were in the lower-price brackets. Prices of cut stones were firm.

(3) GEM DIAMONDS AND THEIR PRESENT TRENDS

LAZARE KAPLAN, *New York, N. Y.*

In recent years the diamond cutting industry has undergone great changes with a dispersal of the industry from Belgium, Holland, and Germany to the far corners of the earth. Diamond cutters are to be found in Transvaal, Palestine, Brazil, and Cuba, and the industry in Puerto

Rico and the United States has expanded more than ten fold. Prior to the war ninety-five per cent of the production of finished stones came from the Low Countries of Europe. No accurate information is available as to the extent of gem cutting in Europe today, but there is every indication that it is almost nil.

During 1941, much of the domestic demand was met by finished stones brought to this country by refugees. By the end of the year many of these refugees had found employment in the older cutting plants or in new establishments which sprang up in this country. The refugees tended to produce the same type of finished product that they cut in Europe. This changed the domestic picture from an industry devoted to the production of larger quality stones to one which produces all gradations of size and quality. In Palestine and Cuba, the newly established cutting plants are producing mainly single cuts (small, round stones with eighteen facets,—table, culet, eight top, and eight bottom facets). Some very fine single cuts are coming from Palestine. In Brazil and Transvaal the emphasis is upon the larger stones.

In this country non-union workers outnumber union workers by about two to one. The Union reported four hundred full-fledged workers and no apprentices in 1940, and in 1942, seven hundred in each category. It is interesting to note that among the apprentices there were fifty women. The women are being used to replace the men who have been called into the armed forces and it is believed that because of the time and money invested in training these women that they will be retained after the war. This assumes that the American industry will be able to compete as favorably with European labor in the production of fine quality large stones after the war as it did before the war. However, it is generally recognized that the cutting of small stones will cease in this country as soon as European competition must be met.

Government ceilings, both on wages and on prices of diamonds under one carat, have caused some dislocations in the industry. The ceiling on wages for any type of work is the highest salary paid to any worker in the shop for that kind of work on the effective date of the ruling. Hence, any shop employing even a single very highly skilled workman is able to outbid his less fortunate competitors. The cost of all imported "rough" has been raised five per cent since the passage of the act, but the producer is able to pass this increased cost on to the buyer only when the finished stone weighs one carat or more. Before the passage of the act there had been a disproportionate increase in the price of small stones over that of the larger stones. A considerable increase in the price of large stones is to be expected in the near future.

The scarcity of large "rough," plus the increased demand in war production areas for jewelry will accentuate this tendency. Further, the inability of the jewelry trade to supply the retailer with those lines such as watches, which require priority materials, leads the jeweler to concentrate his sales efforts on diamonds. The high war-time marriage rate has brought an increased demand for engagement and marriage rings.

Many diamond cutting establishments which in the past have cut only gem diamonds have been called upon to produce specially shaped diamonds for tools, and for use in some types of instruments. The existing industrial diamond-cutting facilities have been unable to supply all of the greatly increased demand for such diamonds and it has been necessary to call upon the gem diamond cutters. The gem cutting branch of the industry will make every effort in the future to meet any demands that may be made upon it for shaped industrial diamonds.

(4) DIAMOND DIES

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During the past twelve months, under the guidance and encouragement of the War Production Board, considerable research work has been carried on in connection with improvement, not only in the quality of workmanship of fine sizes of diamond dies, but also in methods of their production.

The technique of drilling dies has improved greatly as the result of a frequent check of output by means of micro-photographic investigations which revealed flaws in processes and in the quality of workmanship.

Several concerns worked independently on their own development of machines. One of the most outstanding results achieved by one domestic company was caused by its bringing about semi-automatic machines for the drilling of the secondary cone approaching the bearing, and automatic machines for the final drilling of the bearing portion. This company has been honored with an Army-Navy "E" Award for its outstanding contribution in the quality and the quantity of its production.

With the assistance of these specially designed machines, the quantities of 0.0008″- to 0.0015″-size dies produced have increased from an average of under ten dies per month per operator, on conventional equipment, to approximately twenty dies per month per operator, representing an average reduction in labor consumption for all operations from twenty hours to ten hours per die.

While the methods of production of diamond dies were secretively kept by their respective companies—and this position was carefully safeguarded—the WPB, after assuring themselves of the reliability and of the great contribution made by the firm which produced the semi-automatic and automatic machines, effected suitable financial arrangements for obtaining the rights to such machines so as to disseminate this information to all diamond die makers engaged in drilling dies below 0.0015″. As a result, within a reasonably short time, diamond die makers may avail themselves of the best practices which have been developed in the U.S.A. for the production of diamond dies.

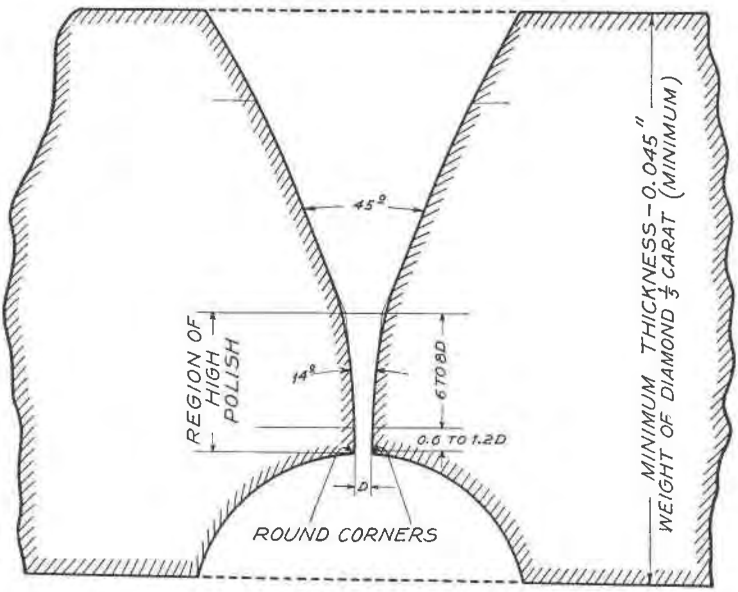

Fig. 1.

In order to establish the proper contours of diamond dies, large quantities of foreign-made dies were carefully analyzed by making numerous photographic enlargements thereof, which resulted in establishing the proper proportions of dies for the sizes under consideration, as shown in Fig. 1.

To aid further our domestic manufacturers, the WPB arranged to take numerous photographs of dies of their own production, as well as those of foreign creation. These photographs were demonstrated at the various plants for the benefit of the respective operators.

At random four representative photographs of diamond dies also have been selected to serve as illustrations in this paper.

Figure 1 indicates the ideal proportions of dies to be drilled. The length of the secondary cone, as well as the length of the bearing, is given in terms of the diameter of the wire which is to be drawn.

Figure 2. This die represents a pattern of an average good execution of a pre-war European die for drawing 0.0008″ wire. The junction of the primary and secondary cones is gently blended. It also indicates the precise centering of the axis of the die bearing and the axis of the cones on either side of the die.

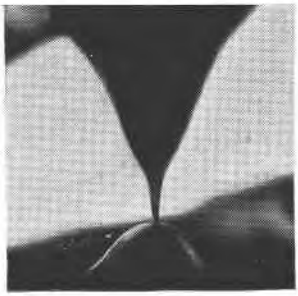

Fig. 2.

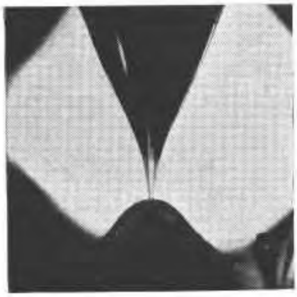

Fig. 3.

Fig. 4.

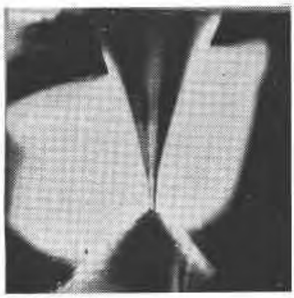

Fig. 5.

Figure 3. This die of 0.0008″ size has been unusually painstakingly executed as to its shape and form. The polish in the secondary cone and throughout the bearing is excellent. The center of the cone, as well as the blending of the contours, is perfect. The shape and execution could be looked upon as a model of perfection.

Figure 4. This die, intended for 0.001″ wire of early domestic production, is a typical die which lacks the secondary cone as well as the bearing. It is well centered but will not produce satisfactory wire and its life will be extremely short.

Figure 5. While this dies has an excellent shape and shows proper blending between the primary and secondary cones, terminating into the bearing with a well centered cone on the back of the die, the pronounced

rings through the portion of the die where the plastic deformation takes place, are objectionable. While it is a well proportioned die, and is intended for 0.0008″ wire, it will probably finish to 0.001″ before the trace of the rings is eliminated.

It is very important that during drilling, proper considerations be given to the size of the grains of the diamond powder employed in drilling. It has been found that the drilling could start with grain sizes of about twenty microns. The polishing of the portion of the die where the plastic deformation of the wire takes place, and particularly the bearing portion, should be polished with diamond powder with grain sizes of approximately one to two microns.

The present facilities available in the United States are about equal to present minimum requirements, and expansion is rapidly taking place. We hope this will provide for maximum future requirements.

(5) DIAMOND-SET TOOLS

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There were no noteworthy developments during 1942 in the use of diamond-set tools. The industry itself was more interested in maintaining production levels to meet the increasing demands than in finding new uses for its products,

Wheel dressing tools, which consist of single uncut crystals mounted at the end of a steel shank, absorbed more of the larger sizes of stones than all other branches of the industry. Although the use of smaller stones mounted in a cast or sintered metal head for dressing wheels has been increasing, diamond core drilling consumes the major portion of these sizes. These two branches of the industry are fairly well stabilized and relatively speaking there is a fair degree of uniformity in the products of different manufacturers.

The future of the development of the diamond tool industry appears to lie in the production of shaped diamond tools for specialized purposes where the unusual properties of the diamond give it a preempted field. The greatest increase in the use of shaped diamond tools in 1942 was in cutting predetermined contours[1] in grinding wheels which in turn are used to grind the reverse contour. Variously shaped "points" were developed to meet the increasing demand for this type of tool, especially, for use on thread grinding machines. These are often roughly lapped and do not require the high degree of skill necessary for the shaping of precision contoured wheels. While the surface is produced by lapping, it perhaps may be more aptly described as a refinement in bruting because it is

[1] Slawson, C. B., Diamond-Set Tools: *Am. Mineral.*, **27**, 180 (1942).

done without reference to the grain of the diamond and is incapable of producing a high polish.

The production of a diamond tool with a predetermined contour is a refinement which calls for a higher degree of skill than the fashioning of gem stones. There are only a few cutters who are capable of producing a polished curved surface with a controlled radius.[2] The chief drawback to the wider use of these tools is their high initial cost, and the inability of most users to make minor repairs. These difficulties could be readily remedied if the tradition of secrecy and exclusiveness which has always surrounded diamond cutting were removed.

The widespread use of the diamond as a cutting tool is further retarded by the lack of knowledge on the part of the mechanic who uses the tool. The industry is still in its infancy and accordingly knowledge of the proper use of diamond-set tools is not widespread. The tendency has always been to use a diamond tool in the same manner in which a metal tool, or more recently a cemented tungsten carbide tool, is used. Today there are a number of specialized uses to which diamond tools are put because others are unsatisfactory. These include the turning of some of the harder woods, ivory, vulcanized rubber, plastics, and materials with a laminated construction. They are also used on many ceramic products and on all the metals except the ferrous alloys.

The statement is commonly made that diamond tools are unsatisfactory when used on the ferrous metals. This should be considered an open question until research proves that they are unsatisfactory at the speeds and feeds which are best adapted to the peculiar properties of the diamond. Further application of the diamond tool, not only in this field but in all others, will depend upon adequate research and the development of a body of common knowledge with respect to its use and abuse. The essential consideration to be borne in mind is that the diamond is a single crystal and not an aggregate of microscopic crystals as is the case with all other cutting materials.

(6) RECENT DEVELOPMENT OF BONDED DIAMOND WHEELS

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During the year 1942, the use of bonded diamond products in industry has expanded tremendously, both through the growth of the older applications and the development of newer applications. In our contribution to the symposium on Diamonds (*Am. Mineral.*, **27**, 185) a tabulation was given showing the relative production of diamond wheels from 1936

[2] Kraus, Edward H., and Slawson, Chester B., Cutting of diamonds for industrial purposes: *Am. Mineral.*, **26**, 154–155 (1941).

to 1941. With the 1936 production taken as 1, the 1941 output was given as 19. By the same comparison, the 1942 figure will reach 53. A brief summary is here given of applications other than that of shaping cemented carbide, which was quite fully discussed in the earlier paper.

The wider field for diamond wheels encompasses the grinding of exceedingly hard and brittle metals and non-metals. In preparing quartz for piezo-electric oscillators, metal-bonded diamond and diamond-impregnated metal wheels are used for the sectioning, trimming, dicing and grinding of these units, and resinoid wheels for finish-grinding the blanks to the desired thickness. The latter operation replaces the more laborious and time-consuming method of lapping with abrasive grain.

The rough grinding of Porro, angular and roof prisms is being done with metal-bonded wheels of a variety of shapes and sizes, and has allowed the manufacturers to introduce mass production methods in the fabrication of these units. It is interesting to note that for the first time in optical industry heavy machine tools for cylindrical grinding and surfacing have been employed in this connection.

The application of metal-bonded wheels as curved generators for the mass production of precision lenses meets the urgent need of our armed forces for such units as binoculars, range finders, and precision watch and optical units. These curved generators are being used for the roughing operation. In ceramics, metal-bonded wheels are being employed for precision finishing of fired ceramic bodies, involving internal, cylindrical and thread grinding, as well as grooving, and surfacing. Even structural brick is being cut commercially with bonded diamond cut-off wheels. Other noteworthy applications are in the internal grinding of cartridge and bullet dies made of Austenitic high-tungsten steel, and in the sectioning and finishing of synthetic sapphire boules for use as bearing jewels.

Finally, mention must be made of the considerable amount of time and attention given to the technology of bonded diamond products. This has resulted in improvements in the composition of metal bonds and in the manufacturing process for both metal and resinoid-bonded articles. A new and quite promising bond for diamonds is being developed. This bond is of the ceramic vitrified type with a high glass content. Vitrified-bonded diamond wheels appear to have some unique properties as compared with the older types.