An Investigation into Manufacturing Processes and Quality Controls in the Ceramic Insert Tool Industry

Anthony Stephen DeSousa II
University of Northern Iowa

An Investigation into Manufacturing Processes and Quality Controls in the Ceramic Insert Tool Industry

Abstract

This study examines the technology and technique that comprises the manufacturing of ceramic insert tools used in the machining environment. This descriptive research was developed by submitting information from actual North American producers of these products and reviewing their processes.

The research examines the types of ceramics produced, the manufacturing processes utilized, ceramic tool machining applications, and a review of the quality control methods that are used within this industry. Numerous manufacturing methods are used in producing ceramic tools. These methods are hot and cold pressing, isostatic pressing, and hot isostatic pressing. Most manufacturers use very high pressure pressing techniques to produce very fine grained and porous free ceramics. Ultrasonic and video graphic forms of defect detection are used along with in-process quality control methods.

The future of ceramic tools is very bright with the advent of higher horsepower machine tools and advances in composite ceramics. These tools are being revisited by users for their custom application abilities.

AN INVESTIGATION INTO MANUFACTURING PROCESSES AND QUALITY CONTROLS IN THE CERAMIC INSERT TOOL INDUSTRY

A Research Paper for Presentation

to the Graduate Faculty

of the

Department of Industrial Technology

University of Northern Iowa

In Partial Fulfillment of the Requirements for the

Non-Thesis Master of Arts Degree

by

Anthony Stephen DeSousa II

Fall, 1991

Approved by:

Dr. J. Fecik Advisor	April 9, 1992 Date
Dr. R. W. Pershing	4-10-92 Date

AN INVESTIGATION INTO MANUFACTURING PROCESSES AND QUALITY CONTROLS IN THE CERAMIC INSERT TOOL INDUSTRY

A Research Paper

Submitted

In Partial Fulfillment

of the Requirements for the

Master of Arts Degree

by

Anthony Stephen DeSousa II

University of Northern Iowa

Fall, 1991

ABSTRACT

This study examines the technology and technique that comprises the manufacturing of ceramic insert tools used in the machining environment. This descriptive research was developed by submitting information from actual North American producers of these products and reviewing their processes.

The research examines the types of ceramics produced, the manufacturing processes utilized, ceramic tool machining applications, and a review of the quality control methods that are used within this industry. Numerous manufacturing methods are used in producing ceramic tools. These methods are hot and cold pressing, isostatic pressing, and hot isostatic pressing. Most manufacturers use very high pressure pressing techniques to produce very fine grained and porous free ceramics. Ultrasonic and video graphic forms of defect detection are used along with in-process quality control methods.

The future of ceramic tools is very bright with the advent of higher horsepower machine tools and advances in composite ceramics. These tools are being revisited by users for their custom application abilities.

TABLE OF CONTENTS

INTRODUCTION

The ceramic insert tool business is a very fascinating and an integral part of the machining industry. There were surprisingly very few firms that make up the list of manufacturers of this type of tooling. Recent and rapid changes in technologies within the nuclear, electronics, and aerospace industries have made people more aware of the versatility of this form of tooling. With advances in machine tools, and the flexibility and productivity required today, ceramic inserts as a viable and acceptable product have been given a second chance by the manufacturing community. The advantages in thermal conductivity, toughness and compressive strengths have opened the doors to new uses and reapplied the technology where it once failed. The introduction of sailons and whisker reinforced ceramics have allowed machine tools to take full advantage of increased horsepower, speeds, and higher removal rates.

This report reviewed the major manufacturers of this form of tooling and related the different techniques and processes that create the end product. The processes were compared by manufacturer and the quality measures that control these processes were investigated.

Statement of the Problem

The problem of this study was to investigate and collate specifically the different manufacturing and quality process controls that are prevalent within the ceramic insert tool industry in North America.

Statement of Purpose

The purpose of this study was to provide insight into the unique and diverse manufacturing processes, methods, and practices that are considered typical and technologically advanced within the ceramic insert industry.

An additional purpose was to explore the quality controls that are being utilized during the manufacturing cycles of this form of product.

This study is appropriate as it addresses the actual operating processes that create a physical product. Manufacturing is nothing more than a composite of detailed steps and procedures (processes) that have been designed for the fabrication of saleable goods or services. These steps become taken for granted because they are the day by day routine ways of life that individuals in manufacturing follow. This study has taken these processes out of the making of an industrial product and highlight it for discussion. This masters degree program in industrial technology was based on an emphasis in manufacturing processes. This fact makes it appropriate that some research be done into this part of the manufacturing cycle.

Statement of Research Questions

The research questions for this study were:

1. What are the controlling manufacturing processes involved in the creation of ceramic insert tooling by todays manufacturers?
2. What quality controls are utilized throughout the manufacturing of ceramic inserts?
3. How is statistical process control being used by todays manufacturers?
4. Is there a preferred method for producing ceramic inserts by the different manufacturers?
5. How varied are the manufacturing processes?

Definition of Terms

The following is a list of specific words and terms as referred to in this document.

1. Ceramic:

Any class of organic, non-metallic products which are subjected to temperatures of 540 C. (1000 F) and above during manufacturing or use, including metallic oxides, borides, carbides, or nitrites and mixtures or compounds of such materials.

2. Sintering:

The bonding of powdered materials by solid state reactions at temperatures lower than those required for the formation of a liquid.

3. Isostatic pressing:

A technique for compacting powders into shapes of high uniform density in which a flexible mold containing powder is sealed in an impermeable envelope and subjected to high and equal pressures from all directions.

4. Process:

A natural phenomenon marked by gradual changes that lead toward a particular result. A series of actions or operations directed toward a particular result.

5. Alumina:

An amphoric material second only to silica in importance to the ceramic industry; acts as a refractory in low temperature products and as a flux in high temperature compositions; used extensively in the manufacturing of abrasives, refractories, white wares, glass and cermets. Examples are spark plugs, clutch and brakelinings,nuclear fuel elements, welding rod coatings, electron tubes, resistors, semiconductors, and gas turbine components.

Statement of Limitations

This study was conducted considering the following limitations.

1. The study was limited to information requested from the following advertisers of ceramic inserts.

   A. Carboloy Metal Cutting Products of Michigan
   B. Kennametal Incorporated of Colorado
   C. Rogers Tool Works Inc. of Arkansas
   D. GTE Valenite Company of Michigan
   E. Certech Inc. of New Jersey
   F. Sandvik Coromant Co. of New Jersey
   G. Toshiba Tungaloy of Illinois
   H. Greenleaf Corporation of Pennsylvania
   I. Kyocera Cutting Tool Division of North Carolina
   J. Teledyne Firth Sterling of LaVerge Tennessee
   K. Hertel Cutting Tools Inc. of Tennessee

2. First hand information, based on observation, was limited to those facilities allowing visitation, and the opportunity to visit due to time and resource constraints.

3. The data was limited to those processes utilized in the manufacturing of ceramic tooling versus the manufacturing of coated carbide or cemented carbide tooling. These processes in many instances are familiar.

4. The quality procedures were limited to those that are applied during the full manufacturing cycle including final inspection. These manufacturing cycles include such processes as the mixing of the powder metals, the pressing, sintering, and final grinding of the completed inserts.

Statement of Procedure

The following outlines the procedures that were used in developing the research needs for this study.

The act of researching was paramount in determining where to go to find companies that produce the kind of product (ceramic inserts) that this study was based on. Along with institutional searches within the reference areas I called on the expertise within the manufacturing engineering and tool design personnel of the John Deere Waterloo Tractor Works of Waterloo Iowa. Another source that was utilized was the varied list of industry periodicals which contain advertising and ceramic manufacturing information.

This information was used to draft introductory letters to key individuals within these companies requesting process information, inquiring about the feasibility of a personnel visit, and requesting information on their applicable quality measures, controls, and procedures. This was followed by telephone interviews to clarify any needs and expand on topics. The processes were identified by manufacturer. The differences and similarities were listed and expounded on.

CHAPTER TWO

Historical Background

The ceramic cutting tool cannot be considered new in accordance to the definition of what a tool represents. The early Egyptians 2500 years prior to Christ used a form of flint tool attached to a stick. These were rotated by hand to bore the openings in vases (King and Wheildon 1966). This activity, by definition, was the first application of a ceramic cutting tool. In 1818 Eli Whitney perfected the first prototype milling machine that used carbon steel cutters with some degree of success. During the last quarter of the nineteenth century hardened tool steels were developed in England and by early 1900's high speed steels were being used in North America. This introduction increased cutting speeds four fold. Ceramics were first applied to the application of machining metals in Germany around 1905 (Tool and Mfg engineers handbook 1983). Some of the first patents for tools were issued in England in 1912 and Germany in 1913. It wasn't until 1935 that some initial study towards potential use was started in this country. In 1943 experimental work with alumina ceramic tools was done at the Institute of Chemical Technology in Moscow. This early work proved that these tools could be beneficial to the machining industry. The first commercial uses weren't available until the 1950's. The slow history of development, 30-40 years between introduction and wide spread usage, was similar to the introduction of other cutting materials. The slow development was partially attributed to lack of understanding, poor quality, misapplication, and the inconsistent and unsatisfactory results that were occurring when trying to alter metals with ceramic tools. What changed all this to todays wider acceptance was an increase in quality brought on by changes in the processes. During this development period quality progressively improved and the environment adapted to accept the new material. Ceramics have improved through better control of their properties, grain refinement, use of additives and better edge preparation due to advanced grinding methods (Shaw, 1984). The cold pressing process used in pure ceramics was developed in the 1930's. This was a cheap and simple method but it produced low density products. In 1944 hot pressing was introduced and the particle density was greatly improved. In 1948 the addition of magnesia improved the density of cold pressing of ceramic inserts to where it was now comparable to hot pressed. Processes improved and in 1968 the submicron or fine grain size of raw materials was reduced improving the toughness and sintering abilities of the ceramics. In approximately 1975 the addition of zirconium upgraded the bulk toughness and ceramics started to receive some acceptance. M Snerringer (personal interview, November, 1992).

CHAPTER THREE

Technical Information

Types of Ceramics

As defined, ceramics are any class of inorganic, non-metallic products which are subjected to temperatures of 540 degrees C and above during manufacture of use, including metallic oxides, borides, carbides or nitrides and mixtures or compounds of such materials (O'Bannon,1984). Most ceramics used in machining are based on high purity fine grained alumina,(aluminum oxide). This compound may contain slightly enhancing additions of zirconia (zirconium oxide), titania (titanium oxide), titanium carbide, or titanium nitride.

The ceramics used in insert tool production were not classified by grade but by type. The composition and processes used to produce ceramic tools allows them to be identified by their color. There are four main divisions within the ceramics that were used in the development of cutting tools (Brookes,1984). The first type was called plain or pure ceramic. These were composed of a highly pure mixture (99% or more) of aluminum oxide Al_2O_3 and may possibly contain only trace amounts of some form of secondary oxides. Alumina is relatively inexpensive, very abundant and extremely good at the removal, machining, and grinding of steel. This ceramic is white in color and is most often produced by a process called cold pressing under high pressure followed by a bonding operation produced by high temperature sintering. A process variation also used in manufacturing pure ceramics involves a method called hot pressing. This procedure combines high pressure and high temperature sintering in a single phase operation and produces a ceramic which is light gray in color.

The second type to be mentioned was called composite ceramics. These were a combination of aluminum oxide and titanium carbide or other alloys. The percentage of components is normally divided into alumina oxide (70% of the total), and the specific alloys making up the remaining 30 %. This 70/30 mix may also consist of alumina and zirconia. This mixture has enhanced properties of strength and shock resistance compared to pure alumina ceramics. Composite ceramics are processed similar to pure ceramics but also include a method called isostatic pressing. This process combines temperatures and pressures, but the pressure is applied unilaterally within a contained environment.

This improves density and minimizes porosity. This process will be discussed in more detail later in this report. Composite ceramics are generally black in color.

The third form of ceramic was another composite, also based on the ingredients of pure ceramics. It combines alumina that has been strengthened by the addition of single crystal silicone carbide whiskers. These whiskers (named for their size comparison to human hair) create a binding reaction during manufacturing and greatly improve toughness and strength. These ceramics are green in color.

The fourth and most recently developed type was a form identified as Sialon (Brookes,1990). This is an acronym for the chemical composition of this ceramic. It stands for silicone (SI) aluminum (AL) oxynitride (ON). This product has a silicone nitride base and was developed by the Lucas Corporation of Great Britain. The first successful application was machining high nickle alloys. The property advantages are very high strength, excellent hot hardness and extreme shock resistance. This form of ceramic is brown in color.

CERAMIC PROPERTIES

The requirements of a good ceramic insert tool have been defined by Brookes (1990) as having minimal porosity, good hardness, chemical stability, high abrasion resistance and shock resistance. The following is a list of desirable elements and attributes that ceramic insert tools have. They are the reasons why ceramics as a material are advantageous to use in certain machining situations.

1. Brittleness/bulk toughness. This is largely determined by the raw materials but also influenced by the production method and overall final density of the ceramic. Toughness was described as the ability of a material to absorb energy without rupture.

2. Hardness. There is no single measurable definition of this attribute but there are a number of characteristics associated with hardness. Hardness can be related to resistance to scratching, resistance to abrasion and wear, machineability, bearing qualities and part resilience.

3. Hot hardness. This is the ability to retain hardness at high temperatures which in machining terms means high speeds. High speed may mean high productivity; based on increased metal removal rates.

4. Thermal shock resistance. This was based on the thermal conductivity and coefficient of thermal expansion of the material. It is the ability to stand

up to rapid temperature changes. This characteristic helps reduce thermal shock cracks in the insert due to thermal expansion.

5. Chemical stability. The stability with the work piece is important regarding wear of the tool. It's ability or designed intention rely on the chemical composition to withstand breakdown from the materials being worked on.

Types of Processes

Depending on the size and configuration of the finished ceramic product, the methods of production are quite numerous and varied. This section described the major processes that are available and the normal manufacturing sequence that is used in creating insert tool ceramics. The general processes that were involved in this manufacturing are sequentially raw material selection, mixing and milling, pressing, sintering, and finish preparation and final grinding.

Raw material selection

The actual raw materials used in manufacturing of ceramics have a pronounced affect on the properties of a usable tool. Different properties are achieved and improved depending on the inert ingredients. The properties most sought after are toughness, strength, hot hardness, thermal shock resistance, and chemical stability. These properties are also influenced by the final density and porosity of the ceramic. This is partially controlled by the pressing or pressurizing method that is utilized.

Mixing/Milling

The actual material density of a finished ceramic is the most critical characteristic reflecting the usefulness of the tool. Proper grinding and thorough mixing of the base powders, alloys, and binders is paramount for successful tool manufacturing. Particle size, shape, and surface activity of alumina powders are factors that have to be controlled during preparation and production of alumina or pure ceramic cutting tools to produce optimum properties. The mixing process is done in an alumina fortified ball mill with an alumina grinding ball to eliminate the possibility of any foreign contamination (Chandler,1968). The milling is controlled to produce grains of material that are similar in size. The grain sizes or material sizes involved are very small. For consideration as a fine or pure ceramic, the grain size must be held to less than 2 or 3 micrometers. After grinding and milling a waxy temporary binder is sometimes added to aid in the pressing process.

Pressing

Ceramic pieces are more difficult to form than metal pieces because of the inherent brittleness and high melting temperatures (Jones and Berard,1972). The forces and pressures that are used to mold the mixed and milled powders into a finished shape are known as pressing. Some of the most commonly used pressing methods are detailed in the following pages.

Cold pressing - The amount of pressure needed in cold pressing is based on the finished density required. An average figure for alumina based tools is 20,000 psi. There is a mathematical calculation developed to represent the forces required to close a pore of material. The formula is 2 X Theta divided by R where theta is the surface tension and R equals pore radius. External pressure revises the model to 2 X theta divided by R plus P which in summary says the greatest forces applied increase the rate of densification. Hydraulic and mechanical presses were used in this process to force or densify the mixed powders into a usable shape. Hydraulic presses are more satisfactory than mechanical because the rate of densification in the die can be regulated better thus reducing the effects of potential layering fractures. Special techniques have also been adopted to advance the cold pressing process. One of these techniques is the use of tungsten carbide dies. These dies are used exclusively for long production runs because of their ability to withstand wear.

Hot pressing - This was another pressing variation used to create higher quality tools. Shaw (1984) states that ceramic powders are pressed at high temperatures normally in graphite dies. This was a slower process but creates a superior product in strength and density compared to cold pressing and subsequent sintering or firing. Hot pressing is similar to the results you get from sintering but allows for rapid densification and is a good technique to produce high quality fine grained specimens. There were four progressive stages that a material goes through during hot pressing. These stages are the repacking of the granuals that initially takes place, the plastic flow of the material, grain rearrangement, and the stress enhancement of actual particle diffusion.

Hot Isostatic pressing - This form of ceramic tool molding needs to be discussed partially by definition. First, the isostatic pressing refers to a force application where the pressure medium is a gas (King and Wheildon,1966). This process was relative to another medium of force called hydrostatic pressing where the force medium is a liquid. The theory of isostatic pressing or molding is based on a pressure applied on a static gas will cause forces to act equally in all directions on the exposed surfaces. The ceramic powder mixture is placed in an elastic container and placed in a pressure chamber. The applied forces in the form of gas are initiated and this unilateral pressure densifies the materials. The rate and pressure are regulated to produce very high quality ceramic products. The containers are made of high strength elastomers. The gas of choice is usually argon. The advantages of this method are very uniform product density, uniform strength in all directions, low equipment costs, and a higher green compact strength than is possible to obtain from any other method. This process was first referred to as gas pressure bonding and demonstrated in 1955 (Region V International Landmark,1985). The original idea was to form a bond between certain materials without changing their shape. The technique was first employed in a material process experiment for an organization to be later known as the Atomic Energy Commission.

Sintering

The next sequential step in the production of insert tooling was the process called sintering. Sintering was defined by O'Bannon (1984) as the bonding of powdered materials by solid state reactions at temperatures lower than those required for the formation of a liquid phase. The critical temperature is maintained and held for a period of time depending on the outcome of the required characteristics. As ceramic strength depends heavily on the size of the flaws present in the finished base materials, special furnaces are needed to heat to high temperatures. These temperatures help to assure fine grain sizes. There was a correlation between heat, grain size, density and the ultimate quality of the insert material (Kubel,1989). There were three main variations within the sintering process. These were conventional sintering, gas pressure sintering, and reaction sintering. In conventional sintering the oven temperatures are controlled to allow transformation at 1500 to 1800 degrees celcius. In gas pressured sintering the ovens are regulated to 1500 to 1800 degree C but also have a controlled atmospheric pressure. This additional pressure is added with gases such as nitrogen and is regulated from 50 to 150 bar. The third variation called reaction sintering uses a reduced oven heat of 1300 to 1400 degrees C. A chemical agent is added which stimulates a reaction and increases the temperatures to over 1800 degrees C.

The properties of alumina insert tools are affected the most by the temperature it was fired at and the time the tool was held at this temperature. Alumina powder compacted materials start to transform at 1200 degrees C. A complete and uniform density is only reached if sintering is completed at temperatures greater than 1700 degrees C. High temperatures and long sintering times are essential to produce a high density product (Cahoon and Christensen,1956). To produce a finer microstructure, lower temperatures and reduced sintering times are needed. Each sintering method produces different characteristics. Some furnaces are gas fired for an oxidizing atmosphere and others are resistance heated for hydrogen atmospheres or to create vacuums.

Grinding and Final finishing

The final stage in the manufacturing of insert tooling was the final grinding and finishing. Here the edge preparation and shape is refined.

Depending on the forming or pressing method used the ceramics were produced in individual pieces, loaves, or blanks. These pressed shapes or blanks were sliced into usable sizes with diamond wheels. The first grinding or slicing is in to rough shapes. Care is taken not to slice the blanks completely through as this might produce chips or small line fractures in the blanks themselves. These would be detrimental to the insert as it would fail under pressure. The disks or sliced blanks were finished on a surface grinder to the desired shape and geometry. Additional edge strengthening of the tool may be necessary. This was done by placing an edge or burr on the actual cutting surface. This was accomplished by tumbling in an abrasive medium or by actual hand honeing. The rough grinding operation is so called because it removes the largest amounts of material. Each pass removes approximately .001 inch of ceramic. The second grinding or finish grinding removes approximately .0002 inch per pass. Certain manufacturers recommend resin bonded diamond wheels for the grinding operations which are quite expensive. They also recommend surface speeds of 3000 feet per minute and the use of a quality high flush coolant system.

Although not always used in the manufacturing of replaceable ceramic insert tooling, there are many varied ceramic production processes. This investigation although limited to the manufacturing processes use to create insert tooling would not do justice to these variations and their importance in the ceramic and powdered metal field without some mention. Without expounding in great detail a partial list of these additional processes is considered necessary.

Wet pressing	Jiggering
Ram pressing	Extrusion
Injection molding	Thixotropic casting
Slip casting	Soluble-mold casting
Dry pressing	Transfer molding
Compression molding	Tape forming
Flame spraying	Green machining
Explosive forming	Isostatic pressing
Hot forging	Hot extrusion

Ceramic Tool Selection Criteria

Successful experiences with ceramic tools relies heavily on their proper selection and application. Many failures and poor opinions on early ceramics were due to misapplication (Brookes, 1990). This form of material removal is not a panacea. It has both advantages and disadvantages depending on proper machining operation and tool selection. In all cases the basic requirements of a good ceramic insert must be met. These include having minimal porosity, good hardness, chemical stability, abrasion resistance, and good shock resistance. According to Krar, Oswald, and St. Amand (1984) ceramic tools are a very good choice and are successfully used for the following situations.

1. High speed single point turning, boring, and facing with continuous cutting.
2. Finishing operations on both ferrous and nonferrous materials.
3. Successful when used on light interrupted finishing cuts on either steel or cast iron. Heavy interrupted cuts are allowable with cast iron only if the work holder and tool support are rigid enough and maintain adequate support.
4. Ceramics are good for machining castings and other forms of abrasive materials that have a tendency to dull or wear down conventional tooling.

5. Ceramics perform well as they have the ability to remove materials with hardness in the range of Rc 66.
6. A good rule of determination is that ceramics work well in any application where control of size and finish is critical and existing tooling is inadequate.

Krar, Oswald, and St.Amand (1984) state that certain disadvantages, or conditions where you should not use ceramics comprise the following.

1. Operations where handling and processes may chip or damage the tooling need to be avoided. Ceramics are very brittle and break easily.
2. As mentioned above they are not always recommended for interrupted cuts because of the shock resistance factor.
3. They have a much higher initial cost factor.
4. They require more rigid machining advancements.
5. Machine horsepower needs are beyond most existing machine tools.

If ceramics are properly chosen and the process designed around their requirements and inherent constraints, tremendous success and productivity is achievable.

CHAPTER FOUR

Current Technology and Quality Controls

Product quality is a challenge of the nineties that cannot be over emphasized. Quality is being determined by the customer at an increasing rate. The dilemma is that each customers interpretation of what quality means to him or his organization may differ. The most effective and productive way to deal with all customers is to provide products that are consistent with the users needs. This process cannot be completed without a design and manufacturing plan that includes in-process and preventative quality controls.

It is unlikely that production quality control techniques will ever be able to guarantee a significantly high yield of ceramics free from flaws and cracks. The inherent nature of ceramics makes them totally intolerant to small cracks and fractures of even less than 100 micrometers. It's basically impossible to prevent 100% of these occurrences from happening. The sensitivity of ceramics to these small flaws is strictly a consequence of their low-fracture toughness compared to most metals.

Because of the above mentioned design considerations, and the expensive nature of the production of ceramic insert tooling, high manufacturing success rates are clearly essential. All phases of the process should be controlled to ensure that fabrication flaws are minimized. Examples of such flaws are porosity from poor grading and processing of raw ceramic powders as well as air entrapment during the pressing or molding of green ceramics. Final grinding and machining procedures need to be monitored to eliminate surface chips and cracks that result from unsatisfactory handling and processing. Additional areas within the ceramic insert process that require attention were the grinding and grading process. Control is needed to insure proper grain and raw material sizes. The pressing method for texture and plastic flow. The drying and sintering process needs to be monitored to insure final product usability. As in most powder metallurgy, the moisture content of the "green body" must be carefully controlled. Proper de-airing before pressing or extrusion was also an essential quality measure. Controlling the temperature and sintering time were very important in regulating the effects on grain size and to reduce any unnecessary crystalline development. It is important that the degree of quality control be determined by the criticality of the application. Because of this there were different variations of quality control on different products and product lines.

Three of the most often used methods of quality control within the ceramics industry are destructive and non destructive testing, proof testing and in-process quality control testing (Srinivasan and Earl,1987). Non destructive testing (NDT) consists of techniques such as X-ray, radiography, ultrasound, penetrant inspection, dimensional examination, youngs modulus measurement, microfocus x-ray, and an advanced technique called refined image enhancement. These tests were used to determine surface and subsurface flaws in finished ceramics. They work well providing good resolution and geometric sharpness. Proof testing, a destructive testing technique, was basically an after the fact test or measurement of the product. This post fabrication inspection is quality assurance of the final product. It was an expensive method but considered effective within ceramic manufacturing quality control. Proof testing exposes the product to conditions comparable to or exceeding the actual end use or service life. A true proof test will include all exact use conditions including temperature, stress, etc. The best precaution that can be taken is to design quality into the process by taking into account the sensitivity of ceramic inserts and the needs and capabilities of the manufacturing process. The third most often used quality method addresses this in more detail. This was the in-process quality control measures. As mentioned by Srinivasan and Earl (1987) the in-process quality checks accomplished during manufacturing are very critical in ensuring the quality of the final product as well as reducing the cost of eliminating rejects at the earliest manufacturing step. The in-process quality control begins with the characterization of incoming powder. Properties such as particle size, size distribution, surface area, surface chemistry, and crystalline form are examples of a good inprocess quality plan The following is a hypothetical example of what a typical process flow plan may look like. The plan includes the process under control and the form of quality control applied.

Process Sequence	Quality Control Method
Alumina Powder Processing	Chemical analysis
	Particle size distribution
Shape forming	Visual and dimensional
	Radiography

Process Sequence	Quality Control Method
Densification	Visual
	Green density
	NDI
	Final bulk density
	Critical property measurements
Final machining	Dimensional.

This type of quality plan along with proof testing and NDT help insure that consistent and reliable products are being manufactured day in and day out.

Robotics are a science that show interesting application uses in the field of ceramic insert manufacturing. The use of robotics in all forms of manufacturing is a reality and is happening everywhere. To include this technology into the ceramic producing efforts would be both appropriate and beneficial. Proper selection is important as the list of models and manufacturers is growing. According to Guha (1982) there were approximately 50 domestic manufacturers producing 90 models and 60 foreign robot manufacturers producing another 150 models. In the not to distant future, the use of robotics may become as essential to the ceramic manufacturing industry, as it is in the automobile industry, in order to stay competitive in the marketplace.

As in all products and services provided today, the need for consistency and repeatability is demanded by an increasingly sophisticated group of consumers. Statistical process control needs to remain within all phases of manufacturing to reduce variation. This is a major requirement for the quality assurance and line control personnel. No longer are these items the responsibility of the quality community as empowerment of the masses is taught and evolves.

Industry Response

One of the first manufacturers to provide detailed information on their manufacturing methods and processes was the Sandvik Coromant Company from New Jersey. They were gracious enough to respond to the request for information. As a company they utilize a variety of different manufacturing methods in the production of ceramic inserts. They defined these methods as follows. Cold Pressing - This involves raw material selection for properties desired and mixing these materials to an equal consistency. The cold pressing application is completed under pressure to assure density and successful sintering. The final process was grinding to desired geometry and periphery. They specified three sintering variations for cold pressing.

Conventional sintering at 1500 to 1800 degrees C.

Gas pressure sintering using temperatures of conventional sintering - 1500 to 1800 degrees C., plus the addition of pressure in the range of 50 to 150 bar.

The third variation was called reaction sintering. This involves heating at 1300 to 1400 degrees C. plus the addition of a chemical agent which stimulates a reaction at around 1500 to 1800 degrees C.

Hot Pressing - This too involves similarities in raw material selection, mixing to desired consistencies, the pressing operation, and speciality grinding. The difference is that heat and pressure are combined in hot pressing. The pressing temperatures are 1400 to 1800 degrees C. and pressure is 25 to 35 MPa. Another key element was that the molds and tools are made of graphite.

Hot Isostatic Pressing - This process was a combination of methods as it involves the raw material selection, the mixing and so forth. The difference begins with first a cold pressing operation then followed by a glass encapsulating and the actual isostatic pressing. In this case the isostatic pressing operation is actually sintering under very high pressure. Sandvik did not provide this pressure requirement. After the isostatic pressing the product is then finish ground to the desired geometry.

Post Hot Isostatic Pressing - This fourth manufacturing method was a combination of cold pressing and hot isostatic pressing or as referred to in industry (HIP). The process sequence starts with material selection and mixing to the required and critical consistency. This is followed by cold pressing at 75 to 200 MPa then sintering at 1400 to 1800 degrees C. The next step was the isostatic pressing under pressure and later the final grinding of chamfers and the periphery.

In summary, the Sandvic Coromat Company utilizes the following manufacturing methods along with the industry abbreviation.

Manufacturing Methods

Cold Pressing	- CP
Hot Pressing	- HP
Hot Isostatic Pressing	- HIP
Post HIP	- CP + HIP

Sandvic applied process controls in all critical portions of the manufacturing of ceramic tools. They stated that quality was a very important and up front field for them. They teach all their operators the basic elements of problem solving, statistics and other quality control practices. They feel this education creates consistency in how their people approach the daily work and overall quality in what they do. They strive to engineer quality into the process rather than inspect it into the final end product.

The second manufacturer to respond to the request for information was the GTE Valenite company in Michigan. Their super abrasives plant is located in Cleveland Ohio. The following information is based on the conversation held on the 26th of November with Mr. Mark Sneeringer. Mr. Sneeringer is a superabrasives staff application engineer with GTE.

GTE Valenite has been producing ceramic and diamond insert tools for approximately forty years. They started out in the mid sixties with initial development and produced some of their first commercial products in the early seventies. They developed and hold the majority of the patents for many of the processes and materials produced today. There speciality is polycrystalline diamond ceramics. They produce three versions.

The first was a diamond to diamond bonding material using a diamond stable resin mixed with ceramic powders. This was heated to between 1200 and 1500 degrees C. and formed under 50-60 kilibars of pressure. The second form was a catalyst based material that under pressure forms a bond with the ceramic base material. This process incorporates hydraulic presses capable of providing force in the range of one million pounds per square inch. The third variation was a CBN or cubic boron nitride ceramic that employs the above mentioned processes. The majority of their forming utilizes hot isostatic pressing. This version as mentioned produces pressing forces in the range of 750,000 to 1,000,000 psi to form the bonding and densification needed for high quality ceramic tools.

The base products were made in disks and cut into the desired shapes. They use either wire cut EDM (electrical discharge machining) or EDG (electrical discharge grinding) to produce the geometries required. All their grinding was done with diamond bonded grinding wheels. Their products were sold individually in disk form or finished form. Many of the inserts were brazed into tool holders and sold in that configuration.

The quality methods applied in their operations were generally statistically based process controls. They did as much up stream defect identification as possible to deter costs. All finish grinding and rough machining dimensions had X bar and range charts being used to plot process variation. They also used different ultrasound and die penetrants to detect surface and subsurface fractures.

In conclusion, GTE is the largest producer of ceramic and superabrasive insert tools in North America. Their products are sold under many different brand names and by other companies using GTE products to fill in their own product lines. The main reason there are so few actual manufacturers is because of the tremendous costs in capital and processing and due to the reality that GTE holds most of the patents to this form of tooling.

CHAPTER FIVE

Future Developments for Ceramic Tools

There is a small revolution happening within the ceramic insert tool industry and machining field. Advances in products and competition in performance cost and reliability are driving ceramics and their uses to new levels of sophistication. There are new forms of ceramic tools with new process names like high performance ceramics, high tech ceramics, and advanced ceramics (Wachtman and McLaren,1985). The development of whisker reinforced ceramics have opened new doors and opportunities for ceramic tools. These new ceramics have dramatically increased overall tool life and productivity.

Improvements in the ceramic field have been directed in the most part to better microstructure control, better grain refinement, the use of additives, and improved grinding and edge preparation techniques. The once known major deficiency of ceramic inserts was their lack of toughness. This problem resulted in chips and breakage of the tool itself under working conditions rather than normal wear. Several improvements have been made allowing for the unique characteristics of ceramics and utilizing these traits. One of the first and most common sense improvements was increasing the working thickness of the insert. The second improvement was to increase the nose radius of the insert to a larger diameter. This helped reduce initial shock and put more bearing on a larger area of the ceramic. The third area of tool improvement has been in the process of tool edge preparation. These combined improvements are consistent with manufacturers recommendations to use round inserts in as many machining applications as you can. You receive all the above mentioned improvements in this one geometry. The redesign of tool holders has helped open the doors for more use and reintroduction of ceramic tools. Machine operators are more willing to try them again or use ceramics for the first time.

Shaw (1984) stated that growth in ceramic insert tool use is expected to increase due to the following factors.

1. The use and development of composites, the sialons and whisker reinforced materials are much less brittle and have tremendous strength and shock resistance that may exceed 100,000 psi.

2. The increased availability of machine tools with higher speeds, (3000 fpm), and greater horsepower,

(exceeding 50 hp) have allowed for full use of ceramic tool advantages..

3. Machine chucks and work piece holding devices have also been designed to incorporate the newer machine tool speeds and increased feed rate capabilities.

4. Refinements in ceramic processing techniques now produce materials of very fine grain sizes and high densification rates. This is the result of new hot pressed and hot isostatic pressing improvements and variations.

New materials are being developed which will provide new areas of improvement to ceramic tools. These materials were combinations of ingredients that show good mechanical properties and fracture toughness. These materials were ceramic fibers combined in a metallic matrix, combined in a ceramic matrix, and ceramic fibers intermixed in a glass matrix. The fiber content is volume controlled and is regulated to 5% of the total mixture. These compounds are creating some interesting characteristics very applicable to machining.

New processing techniques are also being developed. One of the stronger candidates in new ceramic tool production was plasma processing. A plasma is a high temperature (up to 10,000 degrees C) ionized electrical-conducting gas. This technique would be beneficial in reducing sintering times for ceramics which is very time consuming. This process could reduce sintering times and temperatures from 1400 to 1200 degrees and maintain the same results in regards to density versus traditional convection ovens. Usually it takes several hours to sinter a ceramic tool in a convection oven. In a plasma, it can be done in a matter of minutes ("Harnessing Plasma Technology",1991). Peak temperatures will reach in excess of 90 percent of a materials absolute melting point. This process may be one to four years from being a reality. Scientists at the University of Minnesota and at Northwestern University are among those developing plasma systems for sintering ceramics.

CHAPTER SIX

Conclusions and Summary

Research Questions

This section of the conclusion provides answers to the originally asked research questions.

Question number 1: What are the controlling manufacturing processes involved in the creation of ceramic insert tooling by todays manufacturers?

Answer: The controlling processes were the raw material selection and grading, the mixing and milling, the form of pressing or densification, and the sintering or form of bonding technique.

Question number two: What quality controls are utilized throughout the manufacturing process of ceramic inserts?

Answer: Because of the high cost of producing this form of tool, producers use all the process control elements available to them. Rather than proof test after the product is made to see if it meets specifications, they use statistical process control methods throughout the total manufacturing cycle. These methods are being expanded and robotic applications for these type of measurements are being explored.

Question number three: How prevalent is statistical process control being used by todays manufacturers?

Answer: This was essentially answered within question number two. Statistical process controls are well established in the manufacturing of ceramic insert tools. They are so ingrained in the manufacturing cycle and the industry that it goes without saying.

Question number four: Is there a preferred method for producing ceramic inserts by the different manufacturers?

Answer: The preferred method by both North American producers was hot pressing and hot isostatic pressing with very high pressing forces. These forces will range in the area of 1,000,000 psi. This is a very special and limited fraternity of manufacturers. Most of the manufacturing techniques used by both are similar.

Question number five: How varied are the manufacturing processes?

Answer: As shown in the study, there were many different and varied methods and adaptations of methods available in the ceramic manufacturing process. The five or six methods of producing inserts were different than the ten or twelve other ceramic product producing methods.

The size, shape, and requirements of the finished product somewhat dictate the method.

<u>Summary</u>

There were not as many origional manufacturers of this form of tooling than first expected. Many companies that produce other forms of insert tooling sell ceramics but they do not produce them. This was partially due to the specialization in ceramic manufacturing but also due to one manufacturer owning the majority of the patents for material composition and processing technique. There were many more processing variations than originally assumed. The production of ceramics in general is a very old process. From the early days before Christ to the techniques used to satisfy today's aerospace needs, the methods have continued to expand and improve.

The different types of ceramic and polycrystalline materials are theoretically unlimited based on chemical composition. Todays users are custom building these materials to satisfy the new requirements of high speed machining and new material uses. The field of ceramics is experiencing some new growth as former machining users are relooking the applications. Improvements in composition and quality, coupled with improvements in today's machine tools and machining centers have placed ceramic tools in a very good position. The market for these tools should increase as long as processing and engineering types do their job in selecting the most effective and productive machining techniques.

LIST OF REFERENCES

Alford, N., Birchall, J.D., and Kendall,K. (1986, April). Engineering ceramics- the process problem. Materials Science and Technology, pp. 330-339.

Amsted, B. H., Ostwald, P. F. and Begeman, M. L. (1987). Manufacturing processes (8th edition). New York: John Wiley & Sons.

Brandes, E. A. (1983). Smithells metals reference book (6th ed.). London: Butterworths.

Briscoe, E. (1986, September). Ceramics - the fabrication challenge. Materials Science and Technology, pp. 910-912.

Brookes, Kenneth J. A. (1990 March).Guide to the worlds advanced cutting tool materials. American Machinist, vol. 134. pp. 63-67.

Brookes, Kenneth J. A. (1982). World directory and handbook of hardmetals (3rd.ed.). Engineers digest limited and international carbide data

Cahoon, H. P. and Christensen, C. J. (1956). vol 39. Sintering and grain growth in alpha alumina. Journal of American Ceramics Society, pp. 337-344.

Chandler, M. (1968). Ceramics in the modern world. New York: Doubleday.

Charnah, R. M. (1988).The growing pains of ceramic processing (Report) Stafford, England: The Institution of Mechanical Engineers.

DeGarmo, E. P. (1979). Materials and processes in manufacturing (5th edition). New York: McMillian.

Guha, J. K. (1982). Application of robotics in inspection and manufacturing of ceramic products (Report No 9). Cincinnati, Ohio: American Ceramic Society.

Harnessing plasma technology.(1991 December).Compressed Air Magazine. p. 14 - 17.

Jones, J. T. and Berard, M. F. (1972). Ceramics industrial processing and testing. The Iowa State University Press / Ames.

Kane, G. E. (ed). (1982). Modern trends in cutting tools. Dearborne, Michigan: Society of Manufacturing Engineers.

King, A. G. and Wheildon, W. M. (1966). Ceramics in machining processes. New York: Academic Press.

Krar, S. F., Oswald, J. W., and St. Amand, J. E. (1984). Technology of machine tools. New York: McGraw-Hill.

Kubel, Edward J. (1989 September). Good opportunities for advanced ceramics. Advanced Materials and Processes, vol. 135. pp. 55-60.

McColm, I.J. (1983). Ceramic science for material technologists. New York: Leonard-Hill.

Metals handbook.(1989).(9th ed.). vol 16 Machinery. American Society of Metals.

Norton, F. H. (1978). Fine ceramics technology and application. New York: Robert E. Krieger Publishing Company.

O'Bannon, L. S. (1984). Dictionary of ceramic science and engineering. New York: Plenum Press.

Rice,R. W. (1990). Ceramic processing: an overview. AICHE Journal, 36, 481-509.

Region 5 International Landmark. (1985 July). Hot and cold wall hot isostatic processing vessels. Mechanical Engineering, vol. 107. pp. 83-84.

Richerson, David B. (1982). Modern ceramic engineering; properties, processing, and use in design. New York: Marcel Decker Inc.

Shaw, M. C. (1984). Metal cutting principles. Oxford: Clarendon Press.

Sheppard, L. M. (1990). Firing technology heats up for the 90s. Ceramic Bulletin, 10, 1674-1689.

Srinivasan, M and Earl, M. (1987). Quality assurance in manufacturing high-performance ceramics. (Report).

Dusseldorf, Germany: The American Society of Mechanical Engineers. 91.

Tool and manufacturing engineers handbook (vol 1, 4th ed.). (1983). Society of Manufacturing Engineers

Wachtman, John B., McLarren, Malcom G. (1985 February). Advanced ceramics: structural materials with a hot future. Manufacturing Engineering, vol. 94. pp. 56-60.