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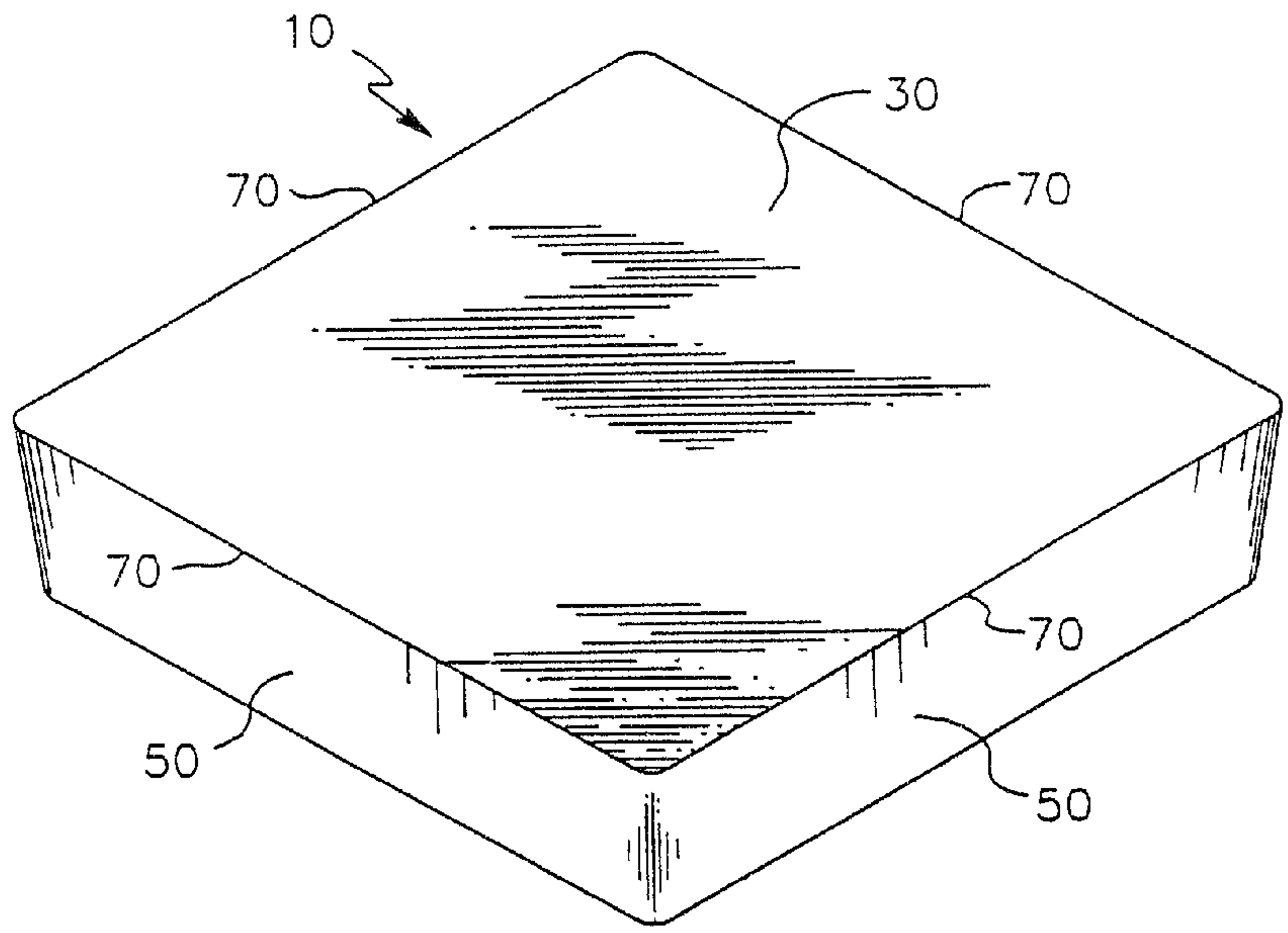
(54) **CERAMIQUE AU NITRURE DE SILICIUM ET OUTIL DE COUPE FAIT DE CE MATERIAU**

(54) **SILICON NITRIDE CERAMIC AND CUTTING TOOL MADE THEREOF**



(57) L'invention se rapporte à une céramique à base de nitrure de silicium que l'on peut notamment utiliser comme outil coupant (10) dans le façonnage par enlèvement de copeaux à grande vitesse de matériaux métalliques. La céramique se compose de préférence d'au moins 85 pour cent en volume (v/o) d'une phase de nitrure de silicium bêta et de moins d'environ 5 pour cent en volume (v/o) de phase intergranulaire. La céramique possède plus de 0,2 pour cent en poids (w/o) de magnésie, plus de 0,2 pour cent en poids (w/o) d'yttria, la somme de la magnésie et de l'yttria étant inférieure à 5 w/o. La céramique possède moins de 0,2 v/o de porosité. L'outil (10) possède une face d'inclinaison (30) réunie aux faces de dépouille (50) par les bords coupants (70).

(57) Provided is a silicon nitride based ceramic which is particularly useful for use as a cutting tool (10) in the high spend chip forming machining of metallic materials. The ceramic is preferably composed of at least 85 volume percent (v/o) beta silicon nitride phase and less than about 5 v/o intergranular phase. The ceramic has greater than 0.2 weight percent (w/o) magnesia, greater than 0.2 w/o yttria, where the sum of magnesia and yttria is less than 5 w/o. The ceramic has less than 0.2 v/o porosity. The tool (10) has a race face (30) joined to flank faces (50) by cutting edges (70).

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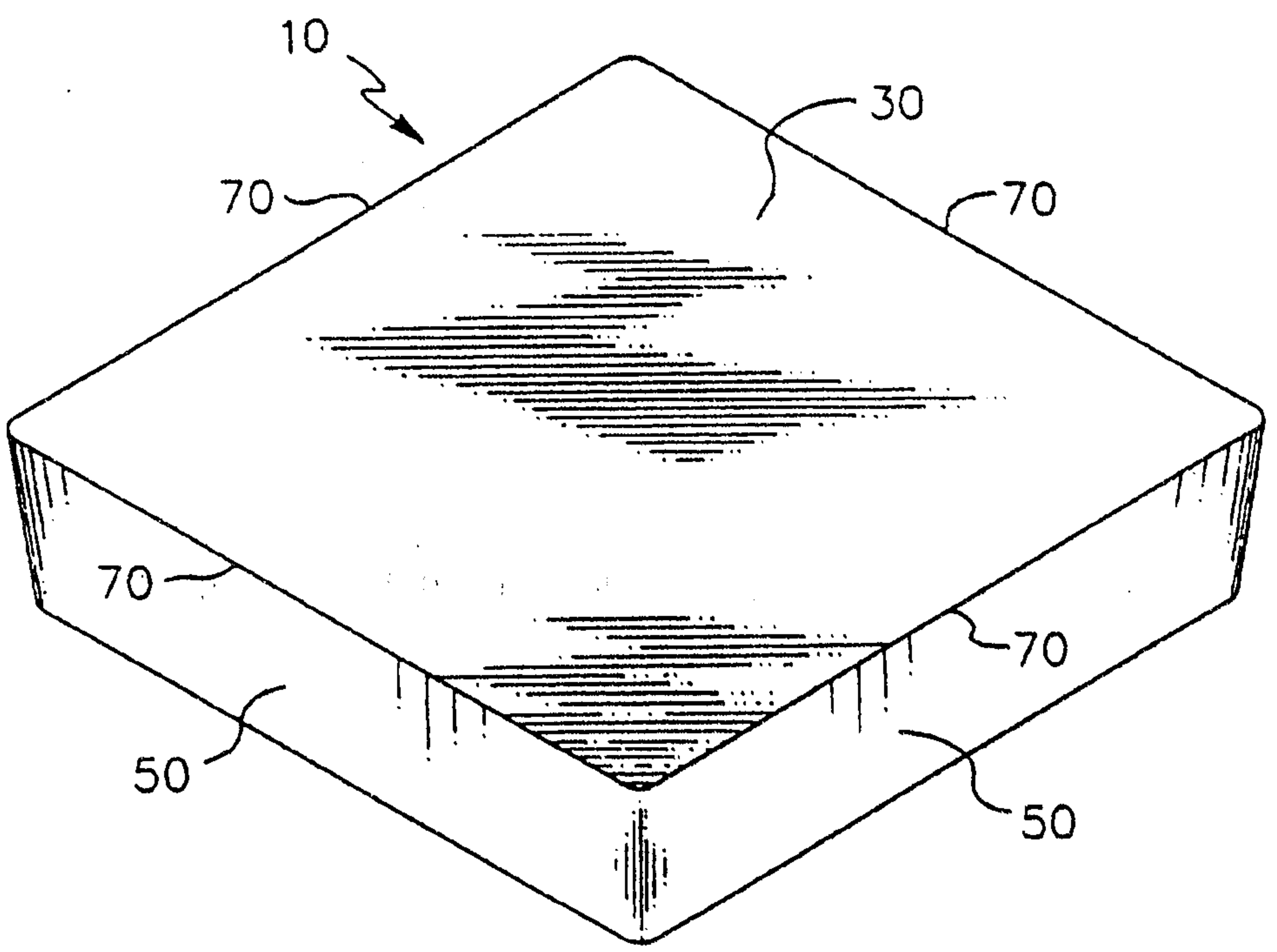

(57) Abstract

Provided is a silicon nitride based ceramic which is particularly useful for use as a cutting tool (10) in the high speed chip forming machining of metallic materials. The ceramic is preferably composed of at least 85 volume percent (v/o) beta silicon nitride phase and less than about 5 v/o intergranular phase. The ceramic has greater than 0.2 weight percent (w/o) magnesia, greater than 0.2 w/o yttria, where the sum of magnesia and yttria is less than 5 w/o. The ceramic has less than 0.2 v/o porosity. The tool (10) has a rake face (30) joined to flank faces (50) by cutting edges (70).

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TITLE OF THE INVENTION

SILICON NITRIDE CERAMIC AND CUTTING TOOL MADE THEREOF

BACKGROUND OF THE INVENTION

The present invention relates to silicon nitride based ceramics and their use, particularly as cutting tools.

In the past, it has been taught by U.S. Patent No. 4,652,276 that beta silicon nitride compositions useful to machine cast iron must contain both yttrium oxide (yttria) and magnesium oxide (magnesia) in the range of 5 to 20 weight percent, total, to obtain long tool life (i.e. improved wear resistance) and improved chipping resistance in the machining of nodular cast iron.

Y_2O_3 and MgO are added in the amounts indicated to produce a glassy intergranular phase during sintering in an amount necessary to the achievement of the proper densification of the ceramic and improved metalcutting performance.

It was found that compositions composed of 98 w/o Si_3N_4 - 1 w/o MgO - 1 w/o Y_2O_3 have poor chipping resistance and poor wear resistance compared to the compositions in accordance with U.S. Patent No. 4,652,276 (see col. 4, Tables I and II).

There, however, remains a need for more advanced silicon nitride ceramics and cutting tools made therefrom which have improved properties and cutting performance, but can also be densified by economical densification methods.

BRIEF SUMMARY OF THE INVENTION

Applicants have now discovered an improved silicon nitride based ceramic composition having improved metal cutting performance, mechanical and physical properties over the prior art.

Their discovery is surprising in that their silicon nitride based ceramic composition contains less than 5 weight percent (w/o) total of yttrium oxide and magnesium oxide, which is contrary to the teaching of the prior art. In addition, despite using a composition which is contrary to the prior art, the present invention preferably and unexpectedly has improved hardness at elevated temperatures such as 1,000°C, and improved transverse rupture strength, and improved Weibull modulus compared to the prior art.

According to one aspect of the present invention there is provided a ceramic cutting tool for high speed chip forming machining of metallic materials, said ceramic cutting tool comprising: a rake face over which chips formed during said chip forming machining of metallic materials will flow; a flank face; a cutting edge, for cutting into said metallic materials at high speeds to form said chips, formed at a junction of said rake face and said flank face; said ceramic consisting essentially of beta silicon nitride phase; and an intergranular phase wherein said ceramic has at least 0.2 w/o yttria and at least 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and wherein said ceramic has greater than 1.3 w/o and up to 3.5 w/o oxygen on an elemental basis, and less than 0.2 v/o porosity.

According to another aspect of the present invention there is provided a ceramic cutting tool for high speed chip forming machining of metallic materials, said ceramic cutting tool comprising: a rake face over which chips formed during said chip forming machining of metallic materials will flow; a flank face; a cutting edge, for cutting into said metallic materials at high speeds to form said chips, formed at a junction of said rake face and said flank face; said ceramic consisting of beta silicon nitride phase and an intergranular phase; wherein said ceramic has greater than 0.2 w/o yttria and greater than 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and less than 0.2 v/o porosity.

According to a further aspect of the present invention there is provided a ceramic consisting essentially of: beta silicon nitride phase and intergranular phase, wherein said ceramic has greater than 0.2 w/o yttria, greater than 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and wherein said ceramic has greater than 1.3 w/o and up to 3.5 w/o oxygen on an elemental basis and less than 0.2 v/o porosity.

According to yet another aspect of the present invention there is provided a ceramic cutting tool for high speed chip forming machining of a metallic material, said ceramic cutting tool comprising: a rake face over which chips formed during said chip forming machining of said metallic material will flow; a flank face; a cutting edge, for cutting into said metallic material at high speeds to form said chips, formed at a junction of said rake face and said flank face; said ceramic consisting essentially of beta silicon nitride phase; and an intergranular phase wherein said ceramic has at least 0.2 w/o yttria and at least 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and wherein said ceramic has 1.3 w/o to 2.2 w/o oxygen and a density of at least 3.19 g/cm^3.

According to yet another aspect of the present invention there is provided a ceramic consisting essentially of: beta silicon nitride phase and intergranular phase, wherein said ceramic has greater than 0.2 w/o yttria, greater than 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, wherein said ceramic has 1.3 w/o to 2.2 w/o oxygen and a density of at least 3.19 g/cm^3.

According to a further aspect of the present invention there is provided a ceramic cutting tool for high speed chip forming machining of metallic materials, said ceramic cutting tool comprising: a rake face over which chips formed during said chip forming machining of metallic materials will flow; a flank face; a cutting edge, for cutting into said metallic materials at high speeds to form said chips, formed at a junction of said rake face and said flank face; said ceramic consisting essentially of beta silicon nitride phase; and an intergranular phase wherein said ceramic has at least 0.2 w/o yttria and at least 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and a density of at least 3.19 g/cm^3.

According to yet another aspect of the present invention there is provided a ceramic consisting essentially of: beta silicon nitride phase and intergranular phase, wherein said ceramic has greater than 0.2 w/o yttria, greater than 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o and a density of at least 3.19 g/cm^3.

These and other aspects of the present invention will become more apparent upon review of the drawings which are briefly described below in conjunction with the detailed description of the invention which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an embodiment of a cutting tool in accordance with the present invention.

Figure 2 shows the hardness of an embodiment of the present invention as a function of temperature.

Figure 3 is a scanning electron micrograph of an embodiment of the present invention showing its microstructure.

Figure 4 is a scanning electron micrograph of a fracture surface of an embodiment of the present invention.

Figure 5 is a graph of cutting tool nose wear as a function of the number of cutting passes for a prior art tool and two embodiments of tools in accordance with the present invention.

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DETAILED DESCRIPTION OF THE INVENTION

In accordance with the present invention, figure 1 shows a preferred embodiment of an indexable ceramic metalcutting insert 10 composed of the silicon nitride based ceramic material discovered by the present inventors. The metalcutting insert 10 is preferably used in the high speed (> 500 surface feet/minute) chip forming machining (e.g. turning, milling, grooving and threading) of metallic materials. This invention is most preferably used in the high speed machining of cast irons (e.g., gray and nodular irons), and is particularly useful in roughing and interrupted cutting of these materials where a combination of high toughness and high wear resistance is required. The metalcutting insert has a rake face 30 over which chips, formed during high speed machining of high temperature alloys and cast irons, flow. Joined to the rake surface 30 are flank faces 50. At the juncture of the rake face and the flank faces 50 is formed a cutting edge 70 for cutting into the high temperature alloys and cast irons at high speeds. The cutting edge 70 may be in either a sharp, honed, chamfered or chamfered and honed condition, depending on application requirements. The hone may be any of the style or sizes of hones used in the industry. Preferably, the cutting edge 70 has a chamfer (i.e., T-land). The cutting insert may also be made in standard shapes and sizes (for example SNGN-434T, SNGN-436T, SPGN-633T, SPGN-634T, inserts may also be made with holes therein as well). The chamfer may typically have a width of .003 to .020 inch and an angle of about 20 to 30°.

The metalcutting insert described above is composed of a silicon nitride composition in accordance with the present invention. This composition has a microstructure of beta phase silicon nitride grains having an intergranular phase or phases disposed

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between the silicon nitride grains. The beta silicon nitride grains preferably form at least 85 v/o of the ceramic and, more preferably, at least 95 v/o. The beta silicon nitride grains have both an equiaxed and an accicular, or needlelike structure and, preferably, have a diameter of less than 1 μm.

The intergranular phase preferably forms about 1 to about 5 v/o of the ceramic and is preferably a glass which is a product of the sintering aids magnesia, yttria, and silicon oxide impurities from the silicon nitride.

The sintering aids used are preferably magnesia and yttria. However, it may be possible to substitute a high temperature oxide such as those of hafnium and the lanthanide series of elements for all or part of the yttria. It may also be possible to substitute calcia for all or part of the magnesia used herein.

There should be at least 0.2 w/o magnesia and 0.2 w/o yttria in the composition of the present invention for sinterability. For cutting insert applications, preferably there should be at least 0.5 w/o magnesia and at least 0.5 w/o yttria to assure adequate densification, i.e., a porosity level below 0.2, and more preferably, below 0.1 v/o. A composition containing 1.0 w/o MgO and 0.5 w/o Y_2O_3 has been found to provide adequate sinterability for cutting insert applications. Therefore, it is preferred that the sum of magnesia and yttria should be at least 1.5 v/o.

As sintering aid content goes up, the hardness of the present invention, both at room temperature and elevated temperatures, goes down. It is, therefore, important that the sum of yttria and magnesia be maintained below 5 w/o. Individually, yttria may be as high as 4.0 w/o and magnesia as high as 4.5 w/o. For the aforementioned reason, it is preferred that the sum of magnesia and yttria be less than 3.5 w/o and, more preferably, less than 3.0 w/o, and most preferably, less than or equal to about 2 w/o. Compositions in the range of 0.5 to 1.5 w/o magnesia and 0.5 to 1.5 w/o yttria have been found to have excellent metalcutting performance in the high speed rough milling of cast irons.

The compositions in accordance with the present invention preferably have a Vickers Hardness Number (VHN, 1 kg load) at room temperature greater than 1700 kg/mm^2 and at 1000°C of greater than 800 and, more preferably, greater than 900 kg/mm^2. The transverse rupture strength of the present invention is greater than 150 and, more preferably, greater than 160 ksi in the 3 point bend test and, preferably, has a Weibull modulus of at least 15. Youngs modulus of the present invention is preferably at least 300 GPa and more preferably at least 320 GPa. The thermal diffusivity (cm^2/sec) is preferably at least 0.2, and the thermal conductivity (cal./sec-cm°C) is, preferably, at least 0.1.

The significant advantages of the present invention are further indicated by the following examples which are intended to be purely illustrative of the present invention.

Cutting inserts of the SPGN-633T style were manufactured using the following techniques. The starting materials, in the proportions shown in Table I were milled for 24 hours with Si_3N_4 media to obtain a BET surface area of about 14 m^2/g and a particle size range in which at least 90% of the powder was less than 1 μm. After milling, the powder was dried, screened and then pelletized using an organic binder.

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TABLE I

Material	Particle Size 90%<(μm)	Nominal Wt.%	Surface Area(BET) m^2/g
Si_3N_4 Grade SN-E10	1.4	98	10-12
Y_2O_3 Grade "fine"	2.5	1	10-16
MgO Grade Light USP/FCC	--	1	40

Grade SN-E10 Si_3N_4 powder is available from Ube Industries, Ltd., of Tokyo, Japan. This powder is equiaxed, has a mean particle size of about 0.2 μm, and is approximately 100 percent crystalline, with greater than 95 percent being alpha silicon nitride and the remainder, if any, is beta silicon nitride. The composition of grade SN-E10 silicon nitride is (in w/o): N>38.0; O<2.0; C<0.2; Cl<100 ppm; Fe<100 ppm; Ca<50 ppm; Al<50 ppm; and the remainder Si.

Fine grade Y_2O_3 is available from Herman C. Starck, Inc., New York, New York. This powder is a high purity powder of at least 99.95% by weight Y_2O_3. The maximum weight percent of metallic impurities is 0.05.

Grade Light USP/FCC, magnesia is available from the Chemical Division of Fisher Scientific, Inc., Fair Lawn, New Jersey. This powder has the following composition: MgO ≥ 96 w/o, Acid insolubles ≤ 0.1 w/o; arsenic ≤ 3 ppm; calcium ≤ 1.1 w/o; heavy metals ≤ .004 w/o; iron ≤ .05 w/o; lead ≤ 10 ppm; loss on ignition ≤ 10 w/o.

After pelletizing, the material was then pill pressed to form green inserts of the desired geometry. The green inserts were then heated in air at 600°F to drive off the fugitive organic binder. Subsequently, the green inserts were sintered utilizing a suitable Si_3N_4 based setting powder for 1 to 2 hours in one

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atmosphere of nitrogen at 1800 - 1850°C. The sintered inserts were then hot isostatically pressed at about 1750°C in a 20,000 psi nitrogen atmosphere to achieve final densification. The resulting inserts were then ground to final size using a 100 or 180 mesh grit size grinding wheel for top and bottom grinding. In this manner, SPGN-633T inserts having a T or K land of .008" X 20° were made. The characteristic properties of this composition are shown in Tables II, III and IV below:

TABLE II

Properties	Invention	Prior Art*
Hardness, Rockwell A		
Range	93.0-94.0	92.8-93.2
Preferred Range	93.3-94.0	
Microhardness VHN (18.5 kg load), GPa		
Range	14.5-15.5	14.2-14.9
Preferred Range	14.7-15.4	
Hot Hardness VHN (1 kg. load) (Kg/mm^2)		
20°C	1772±24	1675±9
200°C	1663±15	
400°C	1475±11	
500°C		1248
600°C	1397±19	
800°C	1268±17	
1000°C	936±16	646±5

*Prior Art composition contains about 2.2 w/o yttrium (2.8 w/o yttria) and about 1.4 w/o magnesium (2.3 w/o magnesia) for a total yttria and magnesia content of about 5.1 w/o.

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TABLE III

	Invention	Prior Art
Chemical Analysis		
O:	1.8-2.9 w/o	3.24 w/o
C:	0.09 w/o	0.55 w/o
Mg:	0.6 w/o	1.43 w/o
Y:	0.7-0.8 w/o	2.19 w/o
Ca:	100 ppm	N.A.
Zr:	<0.01 w/o	<0.01 w/o
Al:	≤ 0.2	0.02 w/o
Fe:	0.01 w/o	0.01 w/o
Density (g/cm^3)	3.19-3.20	3.20
Thermal Diffusivity (cm^2/sec.)	0.205	0.189
Thermal Conductivity (cal/sec-cm°C)	0.114	0.106
Crystalline Phases present: (as determined by X-Ray Diff.)	100±β-Si_3N_4	100±β-Si_3N_4

TABLE IV

	Invention	Prior Art
Fracture Toughness		
K_{Ic} (E&C) (18.5 kg load, Palmqvist Method) $MPam^{1/2}$	7.1-7.5	7.12±.04
Transverse Rupture Strength (3 point bend, 400 grit surface ground) (Ksi)	184.5±10.4	124.1±15.0
Weibull modulus	19.5	8.3
Young's modulus, GPa	300-350	293.5
Shear modulus, GPa	135.8	113.1

Figure 2 shows the elevated temperature Vickers Hardness Number (1 kg load) in kg/mm^2 as a function of temperature in degrees centigrade. As can be seen, at all temperatures from room temperature to 1000°C, the present invention has a higher hardness

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than a prior art Si_3N_4 composition containing 2.8 w/o yttria and 2.3 w/o magnesia.

Figure 3 shows 10,000x magnification view of a metallographically prepared surface of the present invention. The β-Si_3N_4 grains (gray) have a needle-like or accicular form or an equiaxed form. The intergranular phase (white) surrounds the β-Si_3N_4 grains and is estimated to form about 3 to 4 v/o of the material. The needle-like structure of some of the β-Si_3N_4 grains is further emphasized by Figure 4 which shows a scanning electron micrograph at 5000x of a fracture surface from a broken transverse rupture specimen. From these electron micrographs, it can be seen that the average diameter of the β-Si_3N_4 grains is less than about 1 µm.

The SPGN-633T inserts were then tested in the fly cut milling of a gray cast iron engine block (including 6 cylinder bores and cooling channels for a diesel engine) against a prior art Si_3N_4 composition. The prior art composition contains about 2.2 w/o yttrium (=2.8 w/o yttria) and 1.4 w/o magnesium (=2.3 w/o magnesia), for a total magnesia and yttria content of 5.1 w/o. The test conditions were:

Speed:	3000 sfm
Feed:	.006 IPT
DOC:	.080 inch
Coolant:	Dry
Cutter Style:	KDPR 8" 30° lead angle (See Kennametal Milling/87 Catalogue p. 26 (1986))
Length of Pass:	33.75" / Width: 8"

The results of this test are plotted in figure 5, where it can be seen that both inserts in accordance with the present invention, A (100 grit) and B (180 grit), outperformed the prior art material, by achieving a greater number of passes before failure. All inserts failed by chipping. As shown in figure 5,

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the rate of nose wear in the present invention was less than that produced in the prior art. Therefore, as clearly demonstrated by this test, the present invention surprisingly has both enhanced chipping resistance and wear resistance over the prior art in the milling of cast iron under the conditions shown above.

Optionally, the cutting inserts in accordance with the present invention may be coated with a refractory coating for improved wear resistance. It is contemplated that Al_2O_3, TiC and TiN coatings may be applied alone or in combination with each other.

Optionally, the wear resistance of the present invention may also be improved by the substitution of a refractory particulate material for a minor portion of the β-Si_3N_4 phase in the composition. The refractory material may form from 1-35 v/o, and preferably 1-10 v/o of the ceramic composition. Refractory materials which may be dispersed in the β silicon nitride matrix include the nitrides, carbides and carbonitrides of Ti, Hf and Zr, and tungsten carbide as well, alone or in combination with each other.

The present invention is preferably used in the high speed roughing and interrupted cutting of cast irons. There may also be applications in the roughing and interrupted cutting of superalloys where the present invention may perform well. However, most preferably, the present invention is best utilized in the milling of cast irons under the following conditions:

Speed:	500 - 4000 sfm
Feed:	.004 - .020 IPT
DOC:	up to 0.25 inch

By way of definition as used in this specification (unless it is clear from the context that starting powders are being referred to) and in the claims appended hereto, the concentration in weight percent of the yttria (Y_2O_3) and magnesia (MgO) are calculated values based on the concentration of the metallic elements, Mg and Y in weight percent determined by chemical analysis of the densified ceramic. The calculated weight percent of Y_2O_3 is equal to the measured weight percent of Y divided by 0.787. The calculated weight percent of MgO is equal to the measured weight percent of Mg divided by 0.601. It should be understood that no assertion is being made that MgO and Y_2O_3 exist as separate phases in the densified ceramic. The use of oxide concentrations in conjunction with the final densified ceramic is done merely to provide a convenient way of distinguishing the claimed invention from the prior art.

All patents and other publications referred to herein are hereby incorporated by reference in their entireties.

Other embodiments of the invention will be apparent to those skilled in the art from a consideration of this specification or practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with the true scope and spirit of the invention being indicated by the following claims.

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WHAT IS CLAIMED IS:

1. A ceramic cutting tool for high speed chip forming machining of metallic materials, said ceramic cutting tool comprising:

a rake face over which chips formed during said chip forming machining of metallic materials will flow;

a flank face;

a cutting edge, for cutting into said metallic materials at high speeds to form said chips, formed at a junction of said rake face and said flank face;

said ceramic consisting essentially of beta silicon nitride phase;

and an intergranular phase

wherein said ceramic has at least 0.2 w/o yttria and at least 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and wherein said ceramic has greater than 1.3 w/o and up to 3.5 w/o oxygen on an elemental basis, and less than 0.2 v/o porosity.

2. A ceramic cutting tool for high speed chip forming machining of metallic materials, said ceramic cutting tool comprising:

a rake face over which chips formed during said chip forming machining of metallic materials will flow;

a flank face;

a cutting edge, for cutting into said metallic materials at high speeds to form said chips, formed at a junction of said rake face and said flank face;

said ceramic consisting of beta silicon nitride phase and an intergranular phase;

wherein said ceramic has greater than 0.2 w/o yttria and greater than 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and less than 0.2 v/o porosity.

3. The ceramic cutting tool according to any one of claims 1 and 2 wherein the beta silicon nitride phase forms at least 85 v/o of said ceramic.

4. The ceramic cutting tool according to any one of claims 1 and 2 wherein the sum of yttria and magnesia is at least 1.5 w/o.

5. The ceramic cutting tool according to any one of claims 1 and 2 having a hardness at room temperature greater than 1,700 kg/mm^2 and at 1,000°C the hardness is greater than 800 kg/mm^2.

6. The ceramic cutting tool according to claim 1 having a transverse rupture strength greater than 150 Ksi.

7. The ceramic cutting tool according to claim 1 having a Weibull modulus of at least 15.

8. The ceramic cutting tool according to claim 1 having a thermal diffusivity of at least 0.2 cm^2/s and a thermal conductivity of at least 0.1 calorie/sec.-cm °C.

9. The ceramic cutting tool according to claim 1 having a Young's modulus of elasticity of at least 300 GPa.

10. The ceramic cutting tool according to claim 2 wherein the ceramic contains on an elemental basis 1.3 to 3.5 w/o oxygen.

11. The ceramic cutting tool according to claim 1 wherein the yttria is 0.5 to 1.5 w/o, and the magnesia is 0.5 to 1.5 w/o;

wherein the hardness at room temperature is at least 1,700 kg/mm^2 and at 1,000°C hardness is at least 900 kg/mm^2;

wherein the transverse rupture strength is greater than 160 Ksi;

wherein the Weibull modulus is at least 15; and

wherein Young's modulus is at least 300 GPa.

12. The ceramic cutting tool according to any one of claims 1 and 2 wherein the yttria is 0.5 to 1.5 w/o, and the magnesia is 0.5 to 1.5 w/o.

13. The ceramic cutting tool according to any one of claims 1 and 11 wherein the sum of yttria and magnesia is less than or equal to about 2 w/o.

14. The ceramic cutting tool according to any one of claims 1, 11 and 13 wherein the ceramic has a K_{Ic} fracture toughness of 7.1 to 7.5 $MPam^{\frac{1}{2}}$.

15. The ceramic cutting tool according to any one of claims 1, 12 and 13 wherein the ceramic has a hardness of 1,000°C of greater than 900 kg/mm^2.

16. The ceramic cutting tool according to any one of claims 1, 2, 3, 11, 12, 13, 14 and 15 wherein the ceramic contains on an elemental basis 1.8 to 2.9 w/o oxygen.

17. The ceramic cutting tool according to any one of claims 1, 2, 3, 11, 12, 13, 14, 15 and 16 further comprising a refractory coating.

18. The ceramic cutting tool of claim 17 wherein said refractory coating includes Al_2O_3.

19. A ceramic consisting essentially of:

beta silicon nitride phase and intergranular phase, wherein said ceramic has greater than 0.2 w/o yttria, greater than 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and wherein said ceramic has greater than 1.3 w/o and up to 3.5 w/o oxygen on an elemental basis and less than 0.2 v/o porosity.

20. A ceramic consisting of:

beta silicon nitride phase and intergranular phase, wherein said ceramic has greater than 0.2 w/o yttria, greater than 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o and less than 0.2 v/o porosity.

21. The ceramic according to any one of claims 19 and 20 wherein the magnesia is between 0.5 to 1.5 w/o, the yttria is between 0.5 to 1.5 w/o.

22. The ceramic according to claim 19 wherein the sum of yttria and magnesia is less than or equal to about 2 w/o.

23. The ceramic according to claim 21 wherein the porosity is less than 0.1 v/o.

24. The ceramic according to claim 19 wherein the beta silicon nitride phase forms at least 85 v/o of said ceramic.

25. The ceramic according to any one of claims 19, 21 and 23 having a K_{Ic} fracture toughness of 7.1 to 7.5 $MPam^{\frac{1}{2}}$.

26. The ceramic according to any one of claims 19 and 23 having a hardness at 1,000°C of greater than 900 kg/mm^2.

27. The ceramic according to claim 20 containing on an elemental basis 1.3 to 3.5 w/o oxygen.

28. The ceramic according to any one of claims 19, 21 and 23 containing on an elemental basis 1.8 to 2.9 w/o oxygen.

29. A ceramic cutting tool for high speed chip forming machining of a metallic material, said ceramic cutting tool comprising:

a rake face over which chips formed during said chip forming machining of said metallic material will flow;

a flank face;

a cutting edge, for cutting into said metallic material at high speeds to form said chips, formed at a junction of said rake face and said flank face;

said ceramic consisting essentially of beta silicon nitride phase;

and an intergranular phase wherein said ceramic has at least 0.2 w/o yttria and at least 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and wherein said ceramic has 1.3 w/o to 2.2 w/o oxygen and a density of at least 3.19 g/cm^3.

30. The ceramic cutting tool according to claim 29 wherein the beta silicon nitride phase forms at least 85 v/o of said ceramic.

31. The ceramic cutting tool according to claim 29 wherein the sum of yttria and magnesia is at least 1.5 w/o.

32. The ceramic cutting tool according to claim 29 having a hardness at room temperature greater than 1,700 kg/mm^2 and at 1,000° C. the hardness is greater than 800 kg/mm^2.

33. The ceramic cutting tool according to claim 29 having a transverse rupture strength greater than 150 Ksi.

34. The ceramic cutting tool according to claim 29 having a Weibull modulus of at least 15.

35. The ceramic cutting tool according to claim 29 having a thermal diffusivity of at least 0.2 cm^2/s and a thermal conductivity of at least 0.1 calorie/sec.-cm^0C.

36. The ceramic cutting tool according to claim 29 having a Young's modulus of elasticity of at least 300 GPa.

37. The cutting insert according to claim 29 wherein the yttria is 0.5 to 1.5 w/o, and the magnesia is 0.5 to 1.5 w/o; wherein the hardness at room temperature is at least 1,700 kg/mm^2 and at 1,000° C. hardness is at least 900 kg/mm^2; wherein the transverse rupture strength is greater than 160 Ksi; wherein the Weibull modulus is at least 15; and wherein Young's modulus is at least 300 GPa.

38. The ceramic cutting tool according to claim 29 wherein the sum of yttria and magnesia is less than or equal to about 2 w/o.

39. The ceramic cutting tool according to claim 37 wherein the sum of yttria and magnesia is less than or equal to about 2 w/o.

40. The ceramic cutting tool according to claim 29 wherein the yttria is 0.5 to 1.5 w/o, and the magnesia is 0.5 to 1.5 w/o.

41. The ceramic cutting tool according to claim 40 wherein said ceramic has 1.3 to 1.9 w/o oxygen.

42. The ceramic cutting tool according to claim 38 wherein said ceramic has 1.3 to 1.9 w/o oxygen.

43. A ceramic consisting essentially of:

beta silicon nitride phase and intergranular phase, wherein said ceramic has greater than 0.2 w/o yttria, greater than 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, wherein said ceramic has 1.3 w/o to 2.2 w/o oxygen and a density of at least 3.19 g/cm^3.

44. The ceramic according to claim 43 wherein the magnesia is between 0.5 to 1.5 w/o, and the yttria is between 0.5 to 1.5 w/o.

45. The ceramic according to claim 43 wherein the sum of yttria and magnesia is less than or equal to about 2 w/o.

46. The ceramic according to claim 45 wherein oxygen is 1.3 to 1.9 w/o of said ceramic.

47. The ceramic according to claim 44 wherein the beta silicon nitride phase forms at least 85 v/o of said ceramic.

48. The ceramic cutting tool according to claim 29 further comprising a refractory coating on said cutting tool.

49. The ceramic cutting tool according to claim 48 wherein said refractory coating includes Al_2O_3.

50. The ceramic cutting tool according to claim 29 wherein said beta silicon nitride phase forms at least 95 v/o of said ceramic.

51. The ceramic cutting tool according to claim 38 further comprising a refractory coating on said cutting tool, and wherein the refractory coating includes Al_2O_3.

52. The ceramic cutting tool according to claim 51 wherein said beta silicon nitride phase forms at least 95 v/o of said ceramic.

53. The ceramic cutting tool according to claim 49 wherein said refractory coating also includes TiN.

54. The ceramic cutting tool according to claim 52 wherein said refractory coating also includes TiN.

55. A ceramic cutting tool for high speed chip forming machining of metallic materials, said ceramic cutting tool comprising:

a rake face over which chips formed during said chip forming machining of metallic materials will flow;

a flank face;

a cutting edge, for cutting into said metallic materials at high speeds to form said chips, formed at a junction of said rake face and said flank face;

said ceramic consisting essentially of beta silicon nitride phase;

and an intergranular phase wherein said ceramic has at least 0.2 w/o yttria and at least 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o, and a density of at least 3.19 g/cm^3.

56. The ceramic cutting tool according to claim 55 wherein the beta silicon nitride phase forms at least 85 v/o of said ceramic.

57. The ceramic cutting tool according to claim 55 wherein the sum of yttria and magnesia is at least 1.5 w/o.

58. The ceramic cutting tool according to claim 55 having a hardness at room temperature greater than 1,700 kg/mm^2 and at 1,000° c. the hardness is greater than 800 kg/mm^2.

59. The ceramic cutting tool according to claim 55 having a transverse rupture strength greater than 150 Ksi.

60. The ceramic cutting tool according to claim 55 having a Weibull modulus of at least 15.

61. The ceramic cutting tool according to claim 55 having a thermal diffusivity of at least 0.2 cm^2/s and a thermal conductivity of at least 0.1 calorie/sec.-cm^0C.

62. The ceramic cutting tool according to claim 55 having a Young's modulus of elasticity of at least 300 GPa.

63. The cutting insert according to claim 55 wherein the yttria is 0.5 to 1.5 w/o, and the magnesia is 0.5 to 1.5 w/o; wherein the hardness at room temperature is at least 1,700 kg/mm^2 and at 1,000° C. hardness is at least 900 kg/mm^2; wherein the transverse rupture strength is greater than 160 Ksi; wherein the Weibull modulus is at least 15; and wherein Young's modulus is at least 300 GPa.

64. The ceramic cutting tool according to claim 55 wherein the sum of yttria and magnesia is less than or equal to about 2 w/o.

65. The ceramic cutting tool according to claim 29 wherein the sum of yttria and magnesia is less than or equal to about 2 w/o.

66. The ceramic cutting tool according to claim 55 wherein the yttria is 0.5 to 1.5 w/o, and the magnesia is 0.5 to 1.5 w/o.

67. A ceramic consisting essentially of:

beta silicon nitride phase and intergranular phase, wherein said ceramic has greater than 0.2 w/o yttria, greater than 0.2 w/o magnesia, wherein the sum of yttria and magnesia is less than 3.5 w/o and a density of at least 3.19 g/cm^3.

68. The ceramic according to claim 67 wherein the magnesia is between 0.5 to 1.5 w/o, the yttria is between 0.5 to 1.5 w/o.

69. The ceramic according to claim 67 wherein the sum of yttria and magnesia is less than or equal to about 2 w/o.

70. The ceramic according to claim 68 wherein the beta silicon nitride phase forms at least 85 v/o of said ceramic.

71. The ceramic cutting tool according to claim 55 further comprising a refractory coating on said cutting tool.

72. The ceramic cutting tool according to claim 71 wherein said refractory coating includes Al_2O_3.

73. The ceramic cutting tool according to claim 55 wherein said beta silicon nitride phase forms at least 95 v/o of said ceramic.

74. The ceramic cutting tool according to claim 66 further comprising a refractory coating on said cutting tool, and wherein the refractory coating includes Al_2O_3.

75. The ceramic cutting tool according to claim 74 wherein said beta silicon nitride phase forms at least 95 v/o of said ceramic.

76. The ceramic cutting tool according to claim 72 wherein said refractory coating also includes TiN.

77. The ceramic cutting tool according to claim 75 wherein said refractory coating also includes TiN.

78. The ceramic cutting tool according to claim 55 wherein said chip forming machining consists essentially of milling and said metallic material consists essentially of a cast iron.

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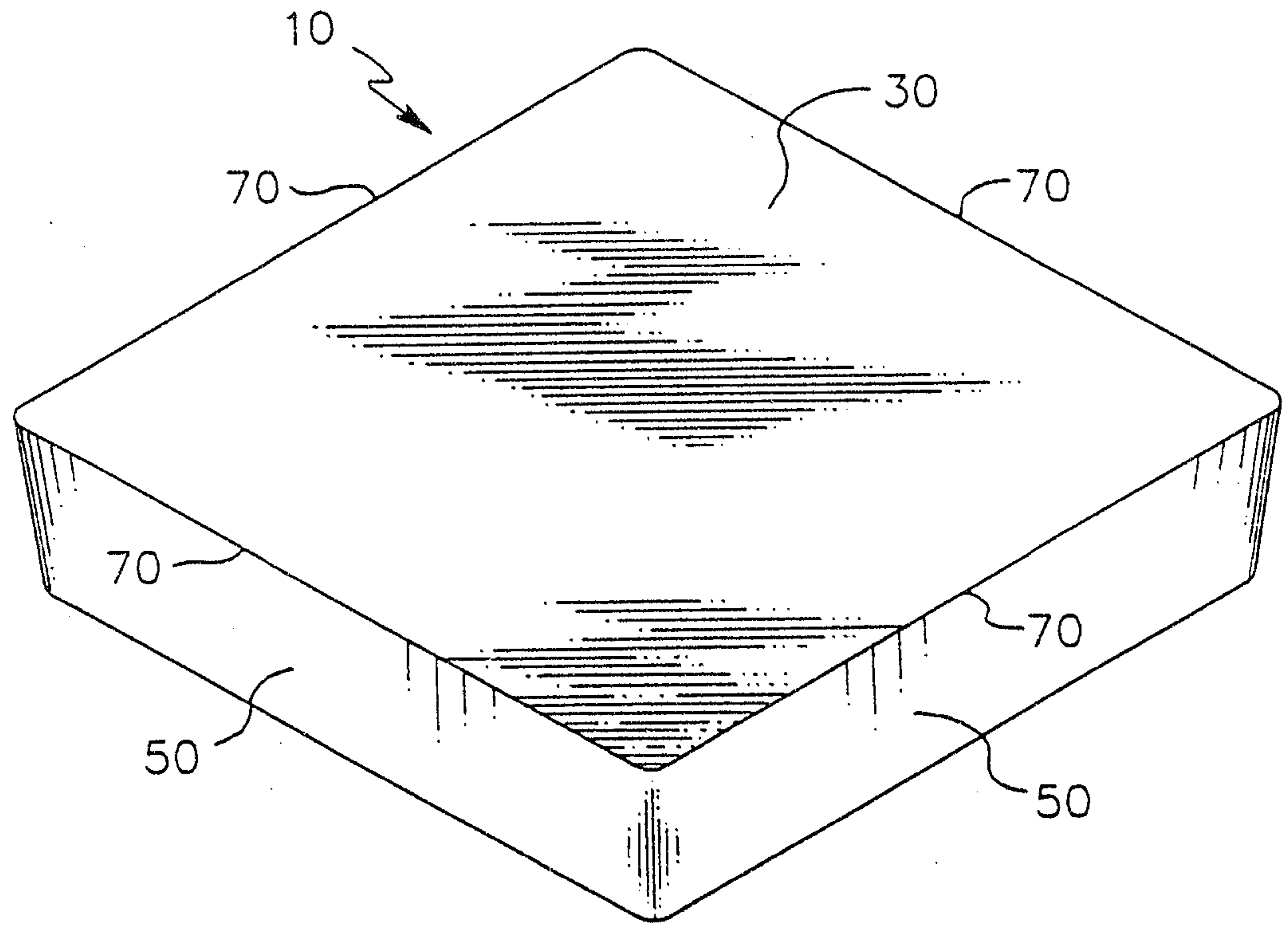

FIG. 1

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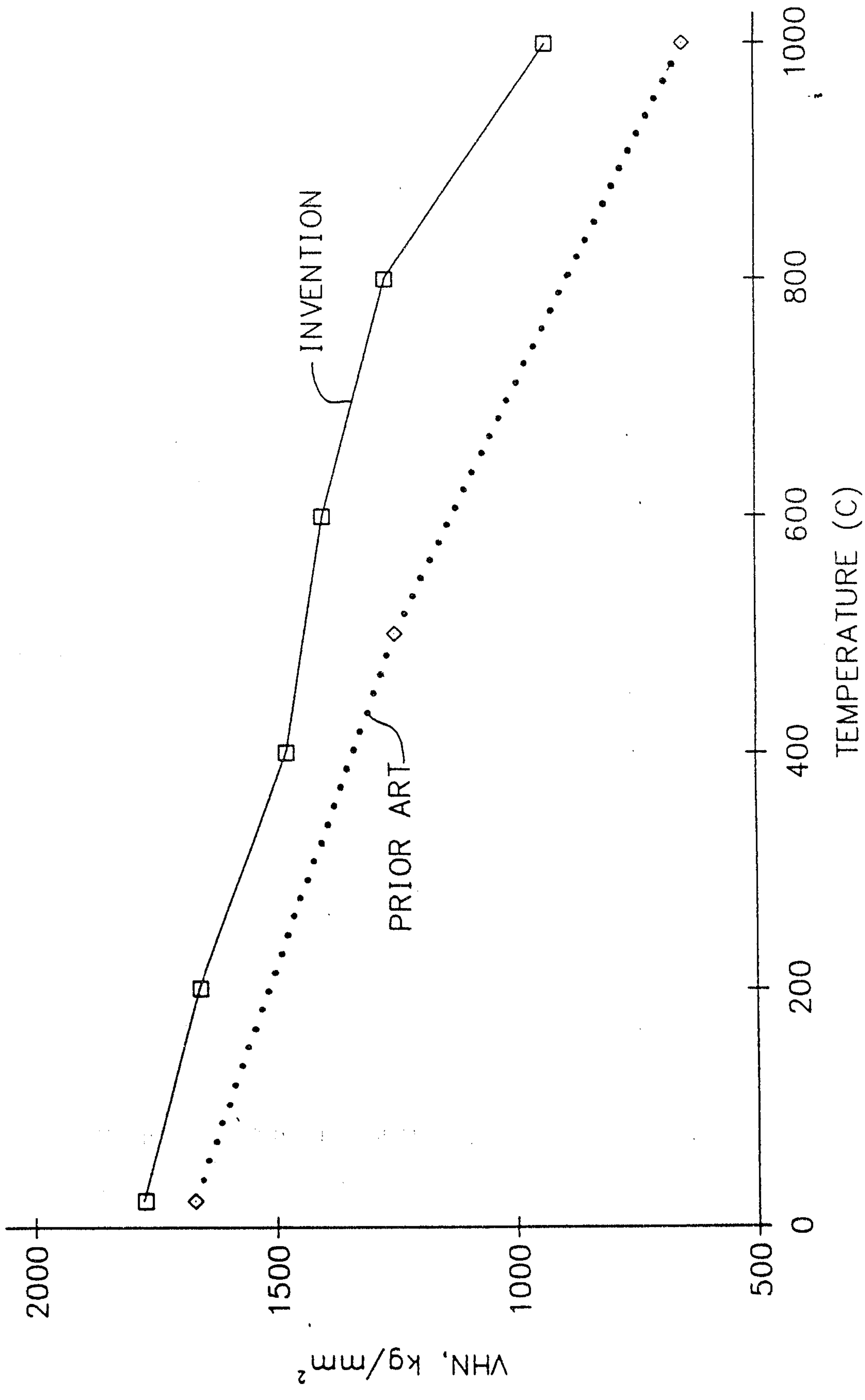

FIG. 2

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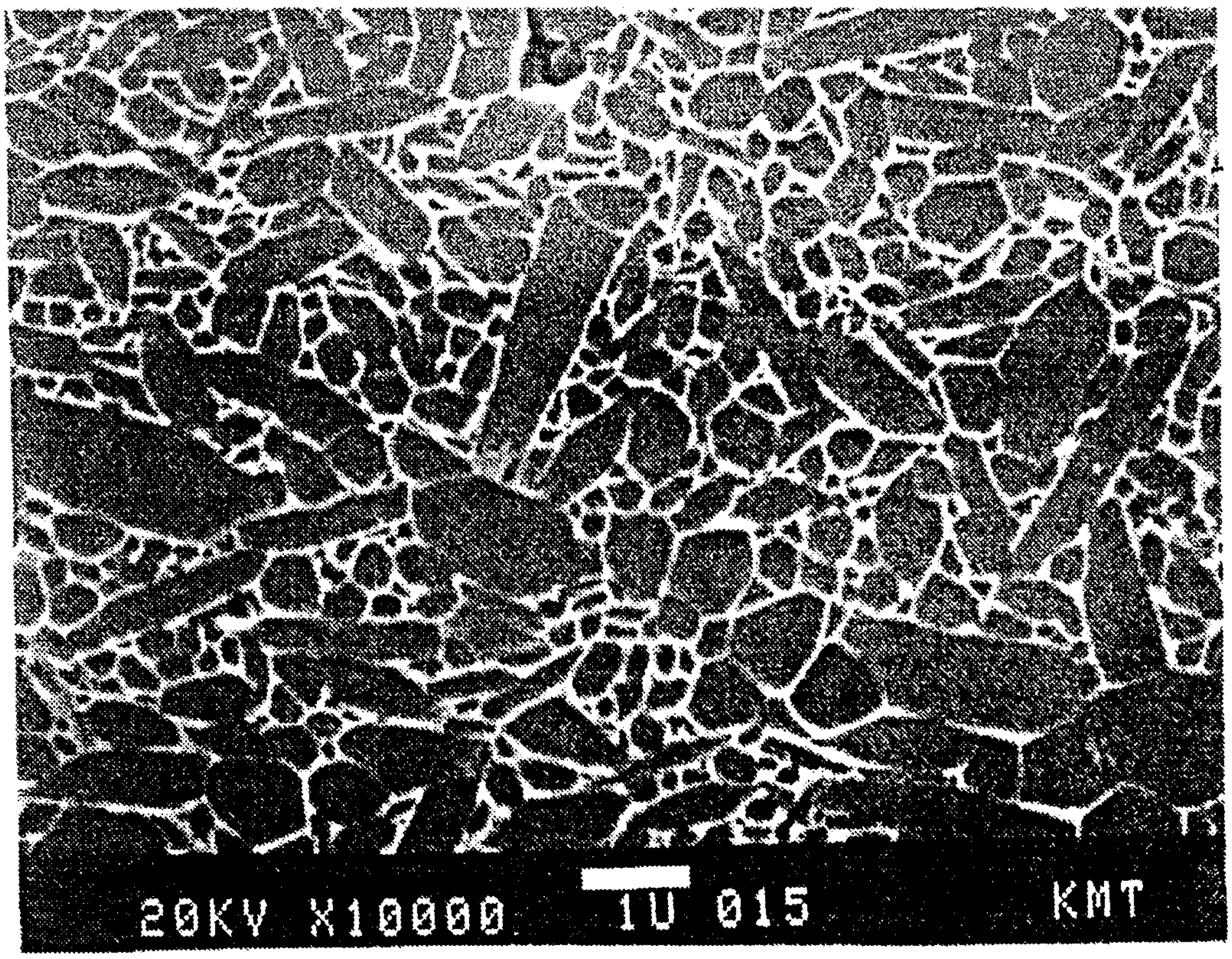

FIG. 3

FIG. 4

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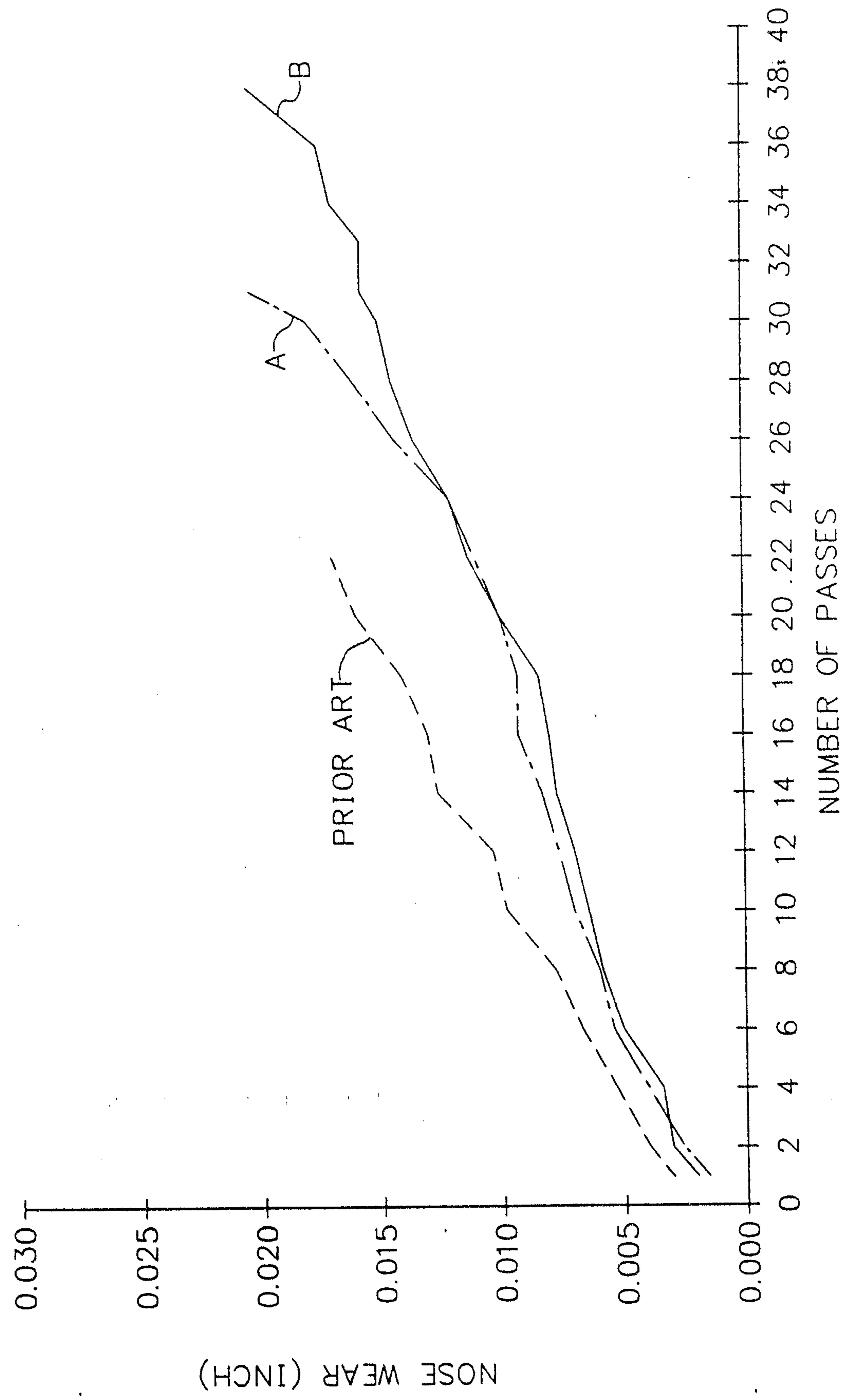
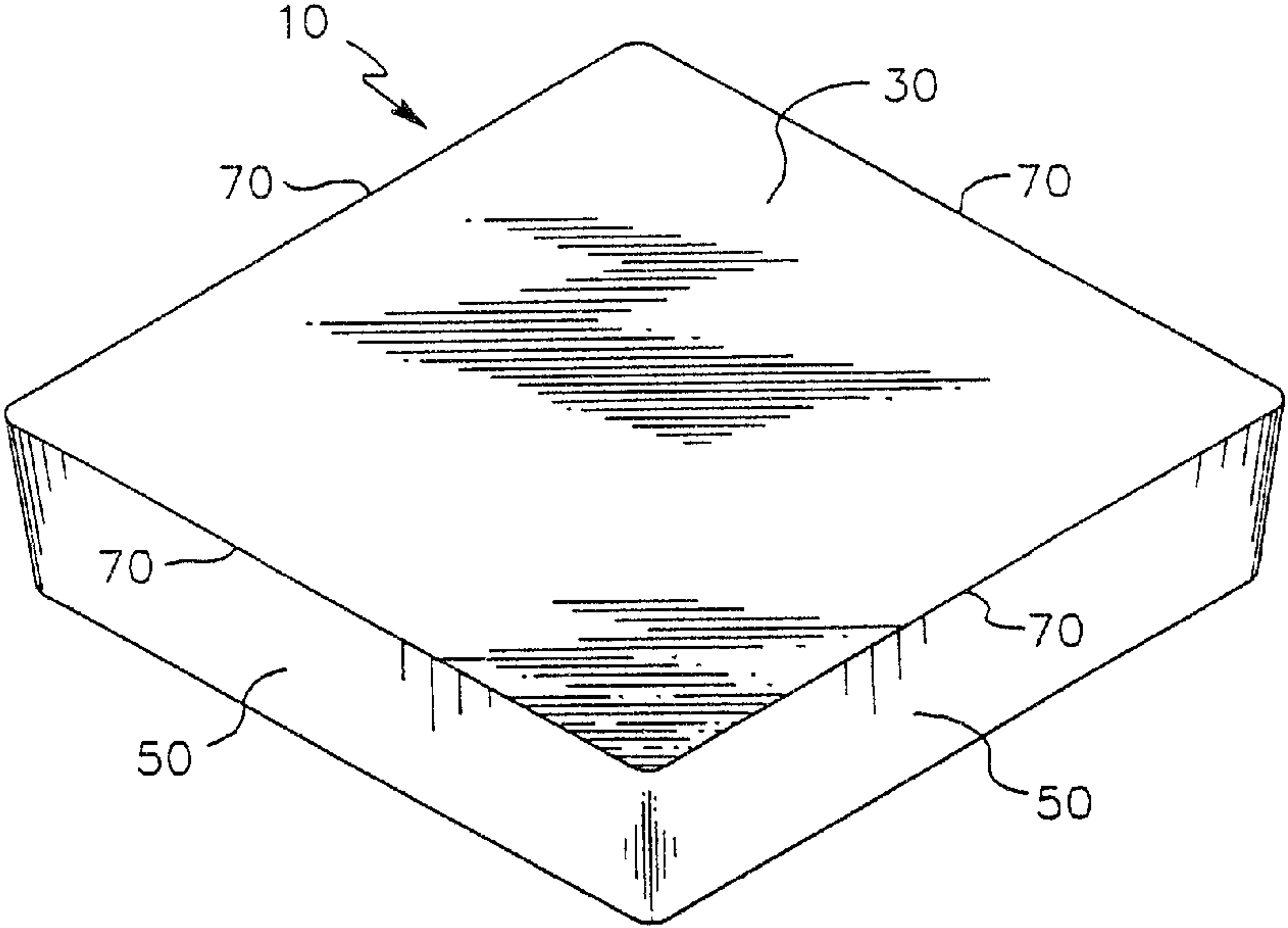


FIG. 5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