



- (51) **International Patent Classification:**
B23P 15/10 (2006.01) *F02F 3/00* (2006.01)
B23K 20/12 (2006.01)
- (21) **International Application Number:**
PCT/EP2015/066009
- (22) **International Filing Date:**
14 July 2015 (14.07.2015)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
10 2014 017407 9 15 July 2014 (15.07.2014) BR
- (71) **Applicants:** MAHLE METAL LEVE S/A [BR/BR]; Rodovia Anhanguera, sentido interior, - capital, km 49,7, 13210-877 Jundiaí (BR). MAHLE INTERNATIONAL GMBH [DE/DE]; Pragstraße 26-46, 70376 Stuttgart (DE).
- (72) **Inventors:** VIEIRA DE MORAIS, Paulo Roberto; Rua Boa Vista, 10, Jd. Represa, 09843-130 Sao Bernardo do Campo, SP (BR). DEZOTTI NETO, Joao Rafael; Rua Comendador Luis José Pereira de Queiroz, 155, 13020-080 Botafogo, Campinas, SP (BR). DA ROCHA MORDENTE, Paulo José; Rua Capitão Curado No. 823, Vila Progresso, 13202-271 Jundiaí, SP (BR).
- (74) **Agent:** BRP RENAUD UND PARTNER MBB; Königstraße 28, 70173 Stuttgart (DE).
- (81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).
- Published:**
— with international search report (Art. 21(3))

(54) **Title:** PROCESS FOR OBTAINING A PISTON AND PISTON SO OBTAINED

(57) **Abstract:** The invention relates in general to a component of an internal combustion engine and more specifically the invention relates to a process for obtaining a piston or manufacturing a groove in a piston for an internal combustion engine. The invention also relates to an internal combustion engine piston obtained by such processes. According to one embodiment of the invention the process of obtaining a piston comprises the stages of: a) providing an internal combustion engine piston; b) carrying out pre-machining of said piston to form at least one circumferential slot along its lateral surface; c) at least partly filling said pre-machined slot with the reinforcing material; and d) subjecting the pre-machined slot filled with reinforcing material to a stir friction process to disperse said reinforcing material in the piston matrix.



WO 2016/008861 A1

"PROCESS FOR OBTAINING A PISTON AND PISTON SO OBTAINED"**FIELD OF THE INVENTION**

[001] The invention relates in general to a component of an internal combustion engine and more specifically the invention relates to a process for obtaining a piston. The invention also relates to a piston for an internal combustion engine obtained by such a process.

BACKGROUND TO THE INVENTION

[002] Internal combustion engines, like engines using the known Otto or Diesel cycles, are extensively and commonly used in vehicles intended for the movement of both persons and goods, such as passenger, transport and goods vehicles, including trucks and locomotives. Briefly these engines use a fuel containing a high concentration of hydrocarbons, such as fossil fuels or fuels from renewable sources, to convert the thermal energy of combustion of the fuel into kinetic energy.

[003] The construction of an internal combustion engine is very well known and basically comprises a piston which moves within a cylinder associated with a crankshaft. Above the piston there is provided a combustion chamber comprising, among other elements such as ribs and/or injection nozzles, at least one inlet valve and one exhaust valve. In turn the piston generally comprises three rings in contact with the cylinder, the two upper rings, that is those closest to the piston head where the combustion gases are compressed in the chamber, having the function of ensuring a seal for the mixture and preventing the escape of both mixture and combustion gases into the interior of the block, and therefore generally being known as "compression rings". The third ring, which is normally located below the compression rings, is designed to remove or "scrape" the oil film as the

piston descends, to prevent oil from being burnt and thus also reduce gas emissions. This ring is generally known as a "scraper" ring.

[004] The components and functioning of an internal combustion engine of both the Otto cycle and the Diesel cycle are commonly known to those skilled in the art, for which reason further explanations in this description are unnecessary.

[005] There is at the present time a growing concern to reduce the emissions produced by internal combustion engines, which are responsible for most of the CO₂ released into the atmosphere. Climate change is one of the most significant environmental challenges at the present time, with possibly serious consequences. This problem is being caused by the increase in the greenhouse effect, which is in turn related to the increase in atmospheric concentration of greenhouse gases (GG), among them carbon dioxide.

[006] In recent years a number of technologies have been incorporated into internal combustion engines to minimize the emission of harmful gases into the environment, such as carbon monoxide (CO), hydrocarbon gases (HC) or nitrogen oxides (NO_x), as well as particulate materials and/or other GG. Reducing gas emissions is related among other factors to increasing the thermal efficiency of engines and consequently reducing specific fuel consumption.

[007] In this respect technologies such as electronic injection, catalysts or particulate material filters are widespread at the present time and used almost compulsorily in all internal combustion engines. Other more recent technologies such as direct fuel injection, or common-rail for motors using the Diesel cycle, and the use on a greater scale of technologies which have been known for a long time, such as mechanical compressors or turbocompressors, are also being used in combination to increase energy efficiency and meet increasingly strict emission standards.

[008] As a consequence combustion engines are developing greater power per piston displacement volume in the cylinder, commonly referred to as power density. On average the efficiency of an Otto cycle combustion engine achieved 50 HP/L during the 1980s, and can now easily reach over 100 HP/L. This means that the combustion pressure within cylinders has increased considerably, which also means that combustion engines are working with greater mechanical forces, higher rotation speeds and a higher combustion temperature. Thus their components likewise have to be dimensioned to withstand these more severe operating conditions in order to ensure both the reliability of the whole and maintain the expected service life, now estimated at approximately 300,000 km for passenger vehicle Otto cycle engines.

[009] This greater operational effort is likewise reflected in greater forces applied to the piston, in particular the grooves provided to receive the rings. With a higher compression ratio, combustion pressure, temperature and rotation speed the rings also exert greater pressure on the piston, which likewise experiences greater wear or fatigue in the grooves, increasing the existing play between the ring and the piston and thus possibly causing problems relating to wear of the cylinder wall and/or the piston, the leakage of oil, increased fuel and/or oil consumption, and even the failure of a ring.

[010] In order to increase the mechanical strength of the piston grooves provided to receive the rings, document GB 382,768 discloses the use of steel or cast iron in the area bearing the rings. Nevertheless this solution increases the weight of the piston, and this has a harmful effect on fuel consumption. Additionally, because different materials are used in the piston, given that pistons are currently manufactured from aluminum or aluminum alloys, this solution commonly gives rise to defects in the piston head which are

frequently not eliminated through subsequent machining, due to the present complex geometry of pistons.

[011] Document JP 2007-064129 discloses the use of a solid state friction stir process (*Friction Stir Processing*) to increase the strength and ductility of the material. However even though this is an advantageous solution it may not be sufficient because of the forces and wear to which internal combustion engines are currently subjected.

[012] The object of the invention is to overcome these disadvantages encountered in the state of the art, among others.

DESCRIPTION OF THE INVENTION

[013] Thus a first object of the invention is to provide a process for obtaining a piston which has improved wear resistance characteristics.

[014] An additional object of the invention is to provide a process for obtaining a piston which has grooves of improved hardness, tensile strength and ductility properties to receive the rings.

[015] In order to achieve the above objects, among others, the invention relates to a process for obtaining a piston which has the stages of:

- a) providing an internal combustion engine piston;
- b) carrying out pre-machining on said piston to form at least one circumferential slot along its lateral surface;
- c) at least partly filling said pre-machined slot with a reinforcing material; and
- d) subjecting the pre-machined slot at least partly filled with reinforcing material to a solid state friction stir process to disperse said reinforcing material into the piston matrix.

[016] In accordance with additional alternative embodiments of the invention the following

characteristics may also be present, alone or in combination:

- said piston is a piston made of aluminum or aluminum alloy;

- said piston is subjected to stages of casting and/or machining and/or shaping prior to stage (a);

- said groove is made of greater width than the width of the slot intended to receive the piston ring;

- said slot is made in approximately the same position as that in which the groove to receive the piston ring is machined;

- in said stage (b) more than one slot is made, in particular 2 slots, and even more particularly 3 slots;

- said reinforcing material is a material in powder form;

- said reinforcing material has a particle size of between 10 nm and 44 μm ;

- said reinforcing material is a ceramic material;

- said reinforcing material is selected from the group comprising alumina (Al_2O_3), silicon carbide (SiC), boron carbide (B_4C), boron nitride (BN), aluminum nitride (AlN), cerium oxide (Ce_2O_3), chromium oxide (Cr_2O_3), silicon (Si) or mixtures thereof;

- said reinforcing material additionally comprises particles of aluminum and/or copper alloys;

- the process additionally comprises the repetition of stage (d) one or more times;

- the process additionally comprises a stage of closing up said pre-machined slot with said reinforcing material after stage (c) and before stage (d);

- said closing up of the slot is brought about through a solid state friction stir process using a tool without a pin;

- said process additionally comprises the stage of producing a groove to receive a piston ring in approximately the same position as that in which said slot is made;

- the process additionally comprises subsequent shaping and/or machining and/or finishing and/or heat treatment stages.

[017] The invention also relates to an internal combustion engine piston which has undergone a process such as that described above during at least part of its manufacture.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[018] The invention will now be described in relation to its particular embodiments. Specific embodiments will be described in detail, on the understanding that these must be regarded as an example of its principles and are not intended to limit the invention to merely what is described in this description. It should be recognized that the different teachings from the embodiments discussed below may be used separately or in any suitable combination to produce the same technical effects.

[019] The processes according to the invention start with the provision of a piston for an internal combustion engine (stage (a)). This piston has previously undergone previous shaping and/or machining and/or heat treatment stages such as, but without being limited to, stages of casting, forging, turning, milling, etc., alone or in combination, regardless of the order in which these stages have been performed. The techniques for the manufacture of an internal combustion engine piston are in themselves known to those skilled in the art, for which reason further details will be unnecessary in this description.

[020] The piston is particularly a piston made from aluminum or an aluminum alloy, such as an Al-Si alloy containing up to 12.5% by weight of Si. The aluminum alloys used to manufacture internal combustion engine pistons are also materials which are well known

in the state of the art, for which reason a detailed description is likewise not necessary here.

[021] The piston then undergoes pre-machining to produce at least one circumferential slot along its lateral wall (stage (b)). It should be understood that in this description the term pre-machining relates to the production of a slot in the piston, but that it is not necessary that this slot should have the final width and depth dimensions of the groove which is made to receive and hold the ring, but has sufficient width and depth to receive reinforcing material (stage (c)). Nevertheless the slot must be made along the entire wall of the piston, forming a circumferential opening in approximately the same location as the finished groove will be formed, which will then be ready to receive the piston ring. This pre-machining of the slot may be carried out by conventional means, such as turning or milling. In particular the slot is made to be of greater width than the groove which will subsequently be machined in order to receive the piston ring, to ensure that all the area where the slot is formed is filled with reinforcing material, as will be made clearer below.

[022] Of course more than one slot may be made if the piston has more than one ring, such as three rings in accordance with the example described above, when it is desired that all the grooves should have excellent hardness, ductility and tensile strength properties. Alternatively for economic reasons, for example, it may be desirable that only one groove has these improved characteristics, such as the groove intended to receive the first compression ring, the other piston rings to receive the second compression ring and the scraper ring being made by known machining methods. In this respect it may be that one or more piston slots undergo the process according to the invention. Additionally the process according to the invention may be applied simultaneously to more than one slot, such as for

example to two or three slots simultaneously, as those skilled in the art will appreciate.

[023] The pre-machined slot is then subsequently partly or wholly filled with a reinforcing material (stage (c)). The reinforcing material may be any material which is suitable for dispersion in the matrix of the piston, such as aluminum or an aluminum alloy, when the slot undergoes the solid state friction stir stage (stage (d)) to form a reinforced area in the area where the groove to receive the ring will be made. In particular the reinforcing material may be a ceramic material placed in the piston slot in powder form. Among the ceramic materials which may be used there are, for example, but without limitation, alumina (Al_2O_3), silicon carbide (SiC), boron carbide (B_4C), boron nitride (BN), aluminum nitride (AlN), cerium oxide (Ce_2O_3), chromium oxide (Cr_2O_3), and their combinations or mixtures. Silicon (Si) may also be used as a reinforcing material, either in or not in association with one or more ceramic materials. Again alternatively the reinforcing material may be combined with particles of aluminum and/or copper alloys in a proportion between 0 and 50% by weight in relation to the total weight of the reinforcing material. These metal particles combined with the reinforcing material may allow the mixture to be more homogeneous when dispersed in the matrix, to improve its strength characteristics even further. The reinforcing material may be placed directly in the pre-machined slot or possibly dispersed using known powder spraying techniques.

[024] The process then continues through subjecting the piston, and particularly the pre-machined area where the reinforcing material has been deposited, to a solid state friction stir process.

[025] Friction stir processing - FSP - is a relatively new technique deriving from the principle of solid state welding by friction and stirring and

basically comprises the application of a rotating tool to a piece in the solid state in order to generate high energy so as to alter the structure of the material. More specifically a cylindrical tool containing a pin of smaller diameter at the tip penetrates the part with high rotation until it comes into contact with the shoulder formed between the pin and the body of the tool. The friction generated at the contact brings about local heating of the part and with circumferential movement of the tool, which is also rotating, brings about intense plastic deformation and stirring of the materials. Thus according to the invention a mixture of the aluminum or aluminum alloy piston together with particles of the reinforcing material is obtained in the matrix. The tool is not consumed because it is made of a harder material.

[026] In this way step (d) assumes that the tool used in the friction stir process is applied to the same area, that is to the slot, in such a way as to ensure that the matrix is mixed with the reinforcing material. Of course step (d) may be repeated one or more times until the reinforcing material is fully fused into the matrix, and likewise the piston may undergo subsequent stages of shaping and/or machining, such as surface finishing stages, for example. It should thus be understood that the process described here is applied within a sequence of other casting, shaping, machining and finishing processes to which an internal combustion engine piston may be subjected.

[027] The process may additionally comprise a stage performed after stage (c) and before stage (d) of closing up the slot. Closing up of the slot which is at least partly filled with a reinforcing material may be desirable because during the solid state friction stir process (stage (d)) it is possible that reinforcing material may be ejected from the slots. In order to avoid this effect and at the same time maintain a high fraction of incorporated particles, the slot may

optionally be closed up with reinforcing material. In particular this closure may be performed using the same friction stir process, but using an alternative tool without a pin. Thus the slot containing the reinforcing material will be closed off at the surface and subsequent processing with the tool containing a pin (stage (d)) will bring about dispersion without the removal of reinforcing material.

[028] The piston may subsequently be subjected to the production of grooves in approximately the same position as that where the reinforcing material was applied, of suitable geometry to receive the ring.

[029] It has been established that the grooves of a piston which have undergone the process according to the invention have a grain microstructure with uniformly dispersed reinforcing particles having an average size of between 1 nm and 44 μm and a fraction of particles of between 2 and 20% by volume.

[030] Tests were performed on the mechanical properties with a reference material, an aluminum alloy, and a component which had undergone the process according to the invention. An improvement in ultimate tensile strength of up to approximately 150% and an improvement in ductility of up to 10% were established, as shown by the results in Table I below. An increase in hardness of at least 20 points on the Vickers scale was also found.

TABLE I

	Sample	Tensile strength (MPa)		Elongation	
		Measured	Mean	Measured	Mean
Untreated aluminum alloy	1	125	129 ± 4.9	0.20	0.22
	2	132		0.23	
Aluminum alloy subjected to the process according to the invention	1	308	309 ± 0.7	2.24	2.18
	2	309		2.11	

[031] Although the invention has been described in relation to particular embodiments thereof, those skilled in the art may apply changes or combinations not contemplated above without diverging from the teaching described here, in addition to expanding it to other applications not considered in this description. The appended claims must therefore be interpreted as covering all and any equivalents which fall within the scope of the principles of the invention.

CLAIMS

1. A process for obtaining a piston characterized in that it comprises the stages of:

a) providing an internal combustion engine piston;
b) carrying out pre-machining on said piston to form at least one circumferential slot along its lateral surface;

c) filling said pre-machined slot at least partly with reinforcing material; and

d) subjecting the pre-machined slot at least partly filled with reinforcing material to a solid state friction stir process to disperse said reinforcing material into the piston matrix.

2. The process as claimed in claim 1, characterized in that said piston is a piston made of aluminum or aluminum alloy.

3. The process as claimed in claim 1, characterized in that said piston undergoes the stages of casting and/or machining and/or shaping prior to stage (a).

4. The process as claimed in claim 1, characterized in that said slot is made with a greater width than the width of the intended groove to receive the piston ring.

5. The process as claimed in claim 1, characterized in that said slot is made in a position which is approximately the same as the position where the groove will be machined in order to receive the piston ring.

6. The process as claimed in claim 1, characterized in that said reinforcing material is a material in powder form.

7. The process as claimed in claims 1 and 6, characterized in that said reinforcing material has a particle size of between 10 nm and 44 μm .

8. The process as claimed in any one of the preceding claims, characterized in that said reinforcing material is a ceramic material.

9. The process as claimed in claim 8, characterized in that said reinforcing material is selected from the group comprising alumina (Al_2O_3), silicon carbide (SiC), boron carbide (B_4C), boron nitride (BN), aluminum nitride (AlN), cerium oxide (Ce_2O_3), chromium oxide (Cr_2O_3), or mixtures thereof.

10. The process as claimed in claim 1, characterized in that said reinforcing material is silicon (Si).

11. The process as claimed in any one of the preceding claims, characterized in that said reinforcing material additionally comprises particles of aluminum and/or copper alloys in a concentration of up to 50% by weight in relation to the total weight of the reinforcing material.

12. The process as claimed in claim 1, characterized in that it additionally comprises the repetition of stage (d) one or more times.

13. The process as claimed in claim 1, characterized in that it additionally comprises a stage of closing up the pre-machined slot with said reinforcing material after stage (c) and before stage (d).

14. The process as claimed in claim 13, characterized in that said closure of the slot is performed by a solid state friction stir process using a tool without a pin.

15. The process as claimed in claim 1, characterized in that it additionally comprises a stage of making a groove to receive a piston ring in a position which is approximately the same as that in which said slot was made.

16. The process as claimed in any one of the preceding claims, characterized in that it additionally

comprises subsequent stages of shaping and/or machining and/or finishing.

17. A piston for an internal combustion engine characterized in that it is subjected to a process as defined in any one of the preceding claims during at least part of its manufacture.

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/066009

A. CLASSIFICATION OF SUBJECT MATTER

INV. B23P15/10 B23K20/12
ADD. F02F3/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B23P B23K F02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/152328 A1 (OKAMOTO KAZUTAKA [JP] ET AL) 18 June 2009 (2009-06-18) paragraph [0073]; figure 7 -----	1-17
X	CN 102 717 243 A (UNIV SHANGHAI JIAOTONG; SHANGHAI LIGHT ALLOY NET FORMING NAT ENGINEERI) 10 October 2012 (2012-10-10) abstract; figures -----	1-17
X	WO 02/01059 A1 (FEDERAL MOGUL TECHNOLOGY LTD [GB]; BARNES SAMANTHA ISOBELLE [GB]; BARN) 3 January 2002 (2002-01-03) page 4, line 13 - line 18 page 8, line 20 - page 9, line 13; figures 15-18 ----- -/-	1,2,17



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

8 September 2015

Date of mailing of the international search report

15/09/2015

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Plastiras, Dimitrios

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/066009

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2003 089884 A (TOSHIBA CORP) 28 March 2003 (2003-03-28) abstract; figure 12 -----	1,17
X	JP 2001 047261 A (SUMITOMO LIGHT METAL IND) 20 February 2001 (2001-02-20) abstract; figure 6 -----	1,17
A	JP 2007 064129 A (NISSAN MOTOR) 15 March 2007 (2007-03-15) cited in the application abstract; figures -----	1,17
A	GB 382 768 A (ERNST MAHLE) 3 November 1932 (1932-11-03) cited in the application claims; figures -----	1,17

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/066009

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009152328 A1	18-06-2009	JP 5149607 B2	20-02-2013
		JP 2009142845 A	02-07-2009
		US 2009152328 A1	18-06-2009

CN 102717243 A	10-10-2012	NONE	

WO 0201059 A1	03-01-2002	AU 7434001 A	08-01-2002
		EP 1295023 A1	26-03-2003
		GB 2367027 A	27-03-2002
		JP 2004502071 A	22-01-2004
		US 2003150418 A1	14-08-2003
		WO 0201059 A1	03-01-2002

JP 2003089884 A	28-03-2003	NONE	

JP 2001047261 A	20-02-2001	JP 3442692 B2	02-09-2003
		JP 2001047261 A	20-02-2001

JP 2007064129 A	15-03-2007	NONE	

GB 382768 A	03-11-1932	NONE	
