SHAPE MEMORY ALLOYS: RESEARCH AND PATENTS IN BRAZIL

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Abstract. *Shape memory alloys are metallic materials that have the capability to recover its original shape eliminating residual deformations when submitted to adequate thermal processes. This behavior is related to phase transformation induced by stress or temperature. Several alloys present this behavior, however only the alloys that are capable to recover large amount of deformations have commercial interest, as nickel-titanium (NiTi) and copper base alloys (CuZnAl and CuAlNi). These alloys have been used in many knowledge areas with applications in bioengineering, automotive and aerospace industry, for example. The purpose of this paper is to present a group of technical information that can be obtained in the Internet databases and that can be used by researches to verify the state of art of a specific technology and by technological managers to support decisions in R&D. In this case it was used as example the topic search "shape memory alloys" in ISI/Web of Science and Derwent Innovations Índex databases. In this preliminary, exploratory and quantitative documental research it was possible to identify: the evolution of the number of publications and patents in the last years; what are being researched and patented; by which instituitions and researchers; and the Brazilian academic production published in international journals.*

Keywords: *shape memory alloys, new materials, patent, technical information, scientific information.*

1. INTRODUCTION

The dissemination of technical information contributes to expand the knowledge base of science and technology (Rackette, 2006). The Committee for a Study on Promoting Access to Scientific and Technical Data for the Public Interest of the National Research Council state that "throughout the history of science, new findings and ideas have been recorded and used as the basis for further scientific advances and for educating students" (National Research Council, 1999).

Nowadays, the New Information and Communication Technologies (NICT) allow quick, low-cost and easy access to virtually all forms of information and data. The dissemination of scientific and technical data, before realized exclusively through printed form, was substituted by electronic form with the use of Internet. This reality has stimulated the creation and exploitation of electronic databases all around the world that has revolutionized the manner in which data are communicated, stored, and manipulated (National Research Council, 1999).

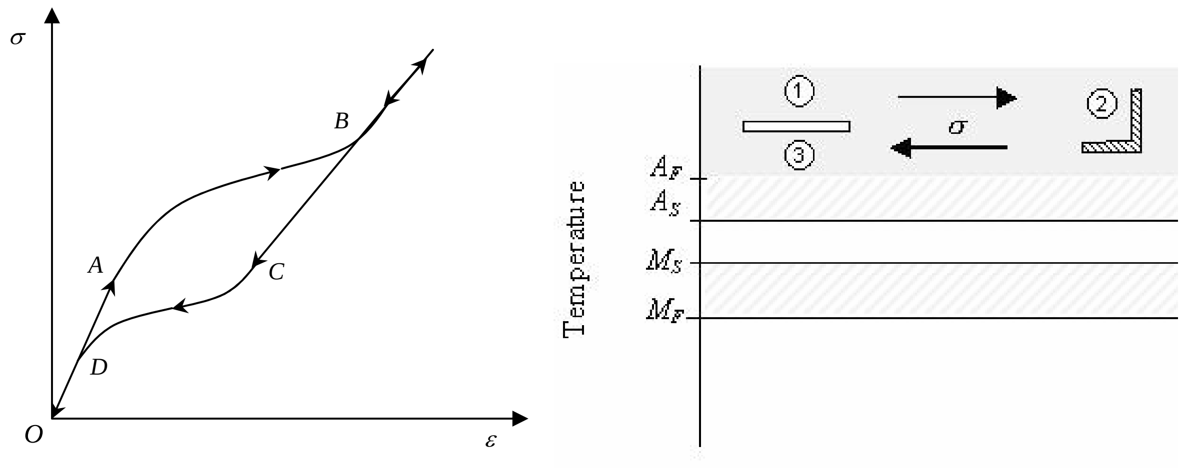
Through of technical information contained in scientific publications and in patent documents it's possible to know what is occurring in a particular technological area, what are the subjects where research is being done, what are the technological trends, what are the emerging research lines, which are the players in a technical field, which are the leading research teams, etc. From these reasons described, it's important to stimulate the scientists and researches to make use of electronic databases that provides quick and easy access (internet) and low cost.

The purpose of this paper is to present the results of a documental research to show some technical information obtained from the Web of Science and Derwent Innovations Index databases, making use of shape memory alloys (SMAs) as topic search. In this exploratory and quantitative research it was possible to identify: the evolution of the number of publications and patents in the last years; what are being researched and patented; by which institutions and researchers; and the Brazilian academic production published in international journals.

2. SHAPE MEMORY ALLOYS

Shape memory alloys (SMAs) have the capability to generate large strains associated to phase transformation induced by stress and/or temperature variations (Hodgson et al., 1992; Rogers, 1995). During the phase transformation process of a SMA component large loads and/or displacements can be generated in a relatively short period of time making this component an interesting mechanical actuator. Two phases are present: martensite and austenite (Zhang *et al.*, 1991). Several alloys can develop strains associated to phase transformation but only those that can develop large strains are of commercial interest, as nickel-titanium (NiTi) and copper base alloys (CuZnAl and CuAlNi). Two basic behaviors are present in SMAs: pseudoelastic and shape memory effects.

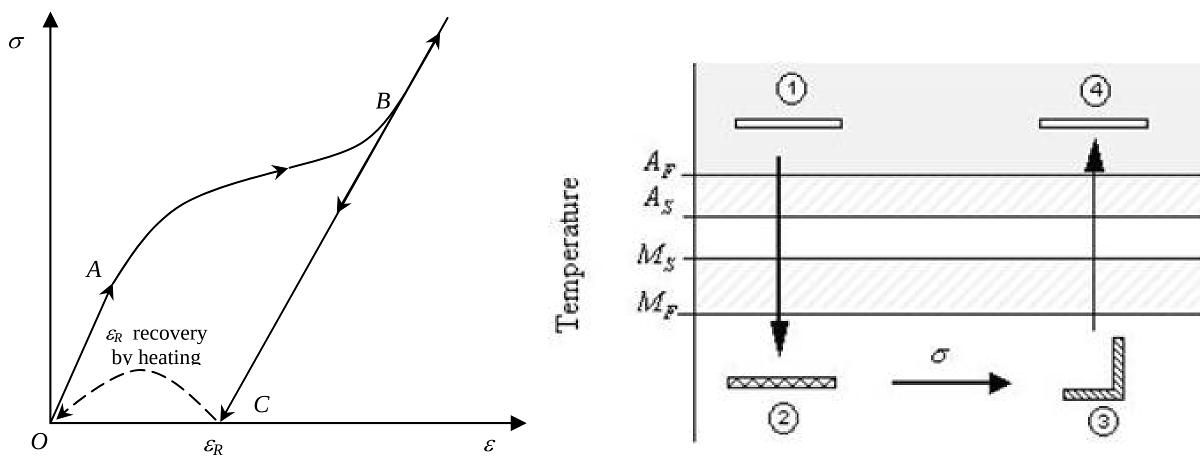
Pseudoelastic effect occurs at higher temperatures, above a critical temperature (A_F) where austenite phase is the only stable phase in a stress-free state. Figure 1*a* presents a stress-strain curve (σ x ε) for the pseudoelastic effect at a constant temperature. In the loading process, a linear behavior (*OA)* is first observed followed by a nonlinear behavior (*AB*) associated to phase transformation (austenite → martensite). After point *B* the presence of 100 % of martensitic phase reveals a linear behavior. In the unloading process a linear behavior is observed until point C is reached. After that, a nonlinear behavior (*CD*) associated to phase transformation (martensite → austenite) is observed followed by a linear behavior associated to the presence of 100% of austenite. Figure 1*b* presents a diagram that illustrates the pseudoelastic behavior. A_S and A_F are the temperatures at which the formation of austenite starts and ends, respectively. M_S and M_F are the temperatures at which the formation of martensite starts and ends, respectively.



(*a*) (*b*)

Figure 1. Pseudoelastic effect. Stress-strain curve (a) and a diagram to illustrate the pseudoelastic effect (*b*).

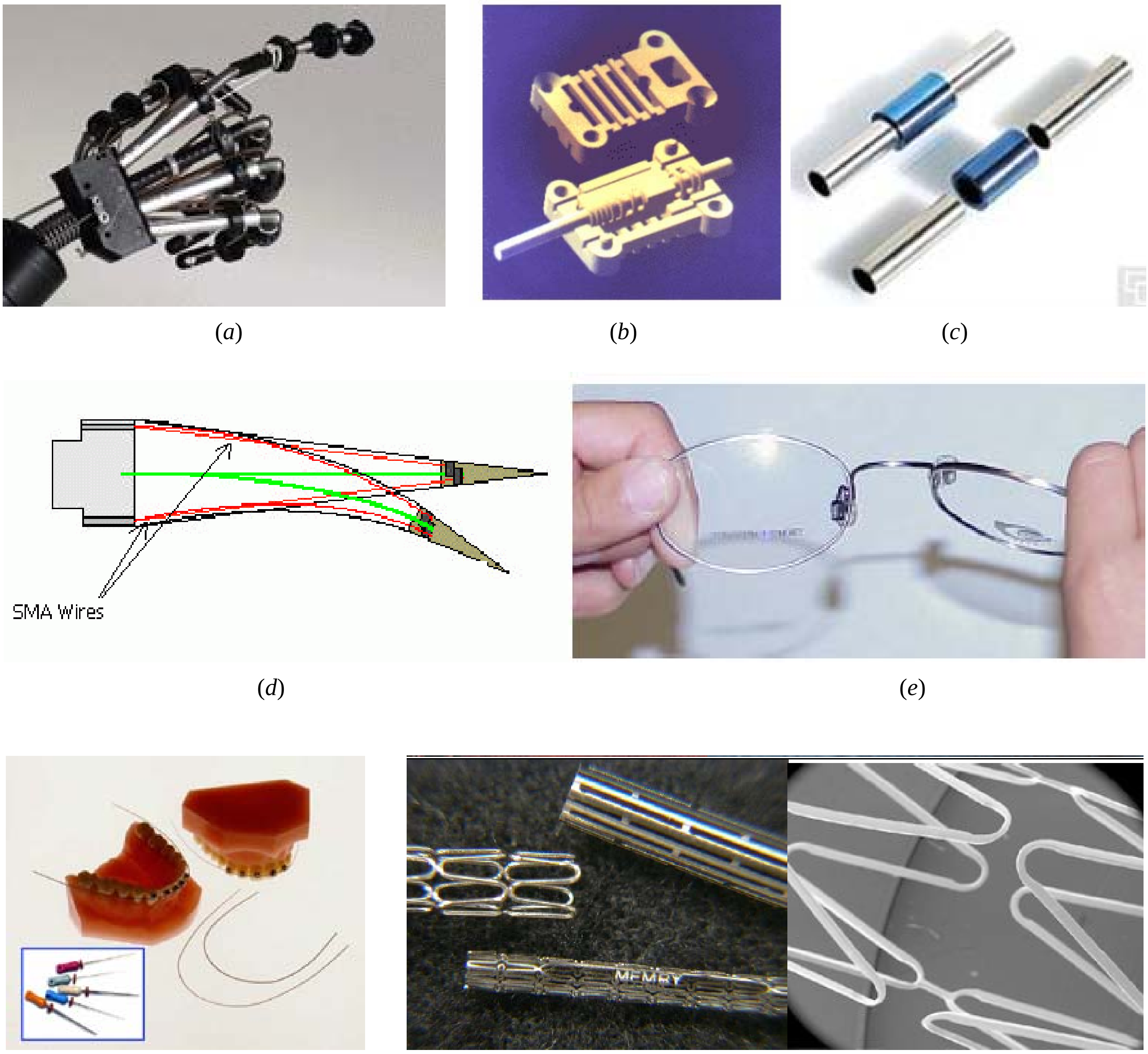
Shape memory effect occurs at lower temperatures, below a critical temperature where twined martensite phase is the only stable phase in a stress-free state (M_F). Figure 2*a* presents a stress-strain curve for the shape memory effect at a constant temperature. For this situation the nonlinear behavior in the loading process is associated to phase transformation related to the conversion from twinned to detwinned martensite. After the unloading process (*C*), some amount of residual strain remains (ε_R), meaning that the reverse transformation, from detwinned to twinned martensite, is not completed. The shape memory effect takes place by heating the alloy, which controls the transformation from detwinned martensite to austenite and promotes the residual strain recovery. Figure 2*b* presents a diagram that illustrates the shape memory effect. M_S and M_F are the temperatures at which the formation of martensite starts and ends, respectively.



(*a*) (*b*)

Figure 2. Shape memory effect. Stress-strain curve (a) and a diagram to illustrate the shape memory effect (*b*).

These remarkable characteristics have been responsible for the increasing interest in different applications varying from biomedical to aerospace industry. Machado and Savi (2003) make a review on the most relevant SMA applications within orthodontics and biomedical areas. They are ideally suited to be used in engineering applications as self-actuating fasteners, thermally actuator switches, seals, connectors and clamps (van Humbeeck, 1999; La Cava *et al.*, 2000). Moreover, aerospace technology is also exploiting SMA properties in order to build self-erectable structures, stabilizing mechanisms, solar batteries, non-explosive release devices and other possibilities (Denoyer *et al.*, 2000; Pacheco and Savi, 1997). Micromanipulators and robotics actuators have been conceived employing SMAs properties to mimic the smooth motions of human muscles (Garner *et al.*, 2001; Webb *et al.*, 2000; Rogers, 1995; Kibirkstis *et al.*, 1997; Chang-jun *et al.*, 2004). Furthermore, SMAs are being used as actuators and absorbers for vibration and buckling control of flexible structures (Birman, 1997; Rogers, 1995; Williams *et al.*, 2002; Campanile *et al.*, 2004; Elzey *et al.*, 2005; Shi *et al.*, 2005). Some SMAs applications covering various fields are presented in Figure 3.



(*a*) (*b*) (*c*)

(*d*) (*e*)

(*f*) (*g*)

Figure 3. SMA applications. Robotic grip (*a*), NiTi spring actuator (*b*), connection sleeve (*c*), hinge-less shape memory alloy flap (*d*), DuraFLEX eyeglasses (*e*), orthodontic wires (*f*) and self-expanding stents (*g*).

3. METHOD

The development of the research was based on searching of the academic production associated to the subject SMAs published in international journals indexed by the ISI/Web of Science and of the requests of patents found in Derwent Innovations Index database.

3.1. ISI/Web of Science

ISI/Web of Science is a powerful research platform available in the Internet and “gives researchers: the freedom to choose from many paths to discover relevant data; the ability to analyze information and perceive overall trends and patters; and the power to construct a complete and wide-ranging picture of available research via one single cross search of complementary resources” (Thomson, 2007). This important database contains current and retrospective multidisciplinary information from approximately 8,700 of the most prestigious, high impact research journals in the world. Therefore, information collected from ISI/Web of Science can be used to asses the state of technique of SMAs research in Brazil and in the World.

The data was collected in the ISI/Web of Science database until April 15th, 2007 and the used parameters are the following: Topic Search: TS = (SHAPE MEMORY ALLOY OR SHAPE MEMORY ALLOYS); DocType = All document types; Languages = All languages; Databases = SCI-EXPANDED, SSCI, A&HCI; Timespan = 1945-2007; and Country/Territory = Brazil or All.

Complementing the search, the item “Refine your results” was used with the following options: Subject Categories; Source Titles; Document Types; Authors; Publication Years; Countries/Territories; Languages; and Institutions.

3.2. Derwent Innovations Index (DII)

Derwent Innovations Index is a searchable database from ISI Web of Knowledge. DII provides access to a comprehensive database of international patent information. DII covers more than 20 million patent documents including the disclosures of inventions from more than 40 patent offices worldwide (Thomson, 2003).

The research was development until April 10th, 2007 and the search parameters are the following: Topic Search: TS = (“Shape Memory Alloy”) searches within articles titles, keywords and abstracts; Databases = Chemical Section, Electrical and Electronic Section and Engineering Section; Timespan = 1963 to 2007.

The purpose of the search in DII was to identify the total of patents and the rankings of the assignees names and the International Patent Classification Codes. Assignees names show the companies that are investing in a specific technology, in this case, shape memory alloy. The International Patent Classification provides for a common classification for patents for invention including published patent applications, utility models and utility certificates. The International Patent Classification (IPC) is a hierarchical system in which the whole area of technology is divided into a range of sections, classes, subclasses and groups. This system is indispensable for the retrieval of patent documents in the search for establishing the novelty of an invention or determining the state of the art in a particular area of technology. The Classification is periodically revised in order to improve the system and to take account of technical development. The current, eighth, edition of the IPC entered into force on January 1st, 2006 (WIPO, 2007). An example of IPC is showed in Table 1.

Table 1. Example of International Patent Classification Application

IPC	Section	Class	Subclass	Group	Subgroup
C22C-019/03	**C** Chemistry; metallurgy	**22** Metallurgy; ferrous or non-ferrous alloys; treatment of alloys or non-ferrous metals	**C** Alloys	**019** Alloys based on nickel or cobalt	**03** based on nickel

4. RESULTS

4.1. ISI/Web of Science: International results

First, international results about SMAs are presented. A search in the ISI/Web of Science database for the topic search TS = (SHAPE MEMORY ALLOY OR SHAPE MEMORY ALLOYS) returns 6,802 results. The first paper was published in 1971. Figure 4 presents the evolution of the number of papers per year from 1971 to 2007. In the 80’s, the number of publications per year presents a small grown but an expressive increase has been observed since the 90´s, reaching more than 850 papers per year in 2006. In 2007, until April 15, there are already 128 documents indexed. The evolution of the number of publications per year presented in Fig. 4 indicates that shape memory alloy is a recent theme and an emerging technology.

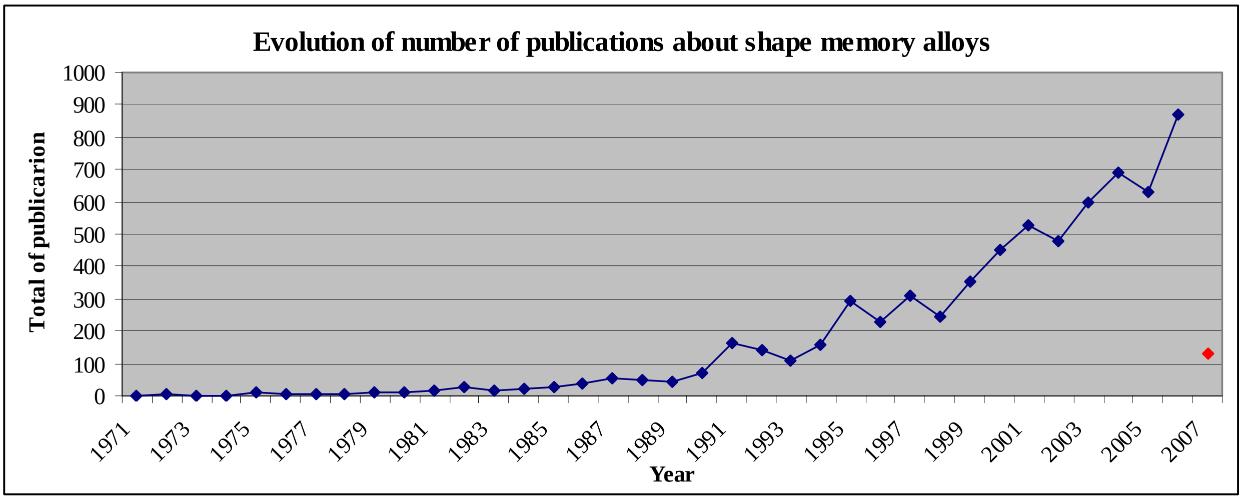


Figure 4. Evolution of the number of publications per year on SMAs from 1971 to 2007

These 6,802 results found can be refined by subject categories and source titles. The ten top subject categories are shown in Table 2 and the ten top source titles are indicates in Table 3. *Materials science* (multidisciplinary) and *metallurgy & metallurgical engineering* are the principal subject categories followed by *nanoscience & nanotechnology*. The source title that contains the largest number of publications about SMAs is *Materials Science A-Structural Materials Properties Microstructure and Processing* and is followed by the *Journal de Physique IV*.

Table 2. Top Subject Categories

Subject Categories	Total	Subject Categories	Total
Materials Science, Multidisciplinary	3,646	Physics, Condensed Matter	552
Metallurgy & Metallurgical Engineering	1,934	Mechanics	471
Nanoscience & Nanotechnology	858	Instruments & Instrumentation	324
Physics, Applied	665	Engineering, Mechanical	265
Physics, Multidisciplinary	598	Chemistry, Physical	244

Table 3. Top Source Titles

Source Titles	Total	Source Titles	Total
Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing	587	Materials Transactions	173
Journal de Physique IV	494	Journal of Intelligent Material Systems and Structures	156
Scripta Materialia	239	Journal of Alloys and Compounds	106
Smart Materials & Structures	188	Shape Memory Materials and Its Applications	105
Acta Materialia	177	Journal of Materials Science	92

Japan, USA and China are the three countries with the larger number of publications on SMAs (1,335, 1,256 and 1,241, respectively) indexed in the ISI/Web of Science database. Brazil is in 23rd position in the ranking with 54 publications. Table 4 shows the firsts 30 top countries/territories in the ranking and their total publications on SMAs.

Table 4. Top Countries/Territories

Countries/Territories	Total	Countries/Territories	Total	Countries/Territories	Total
Japan	1,335	Canada	164	India	101
USA	1,256	England	161	Switzerland	99
Peoples R China	1,241	Belgium	160	Brazil	54
Germany	490	Taiwan	143	Austria	53
France	483	Argentina	140	Turkey	45
Spain	396	Singapore	140	USSR	35
Russia	325	Poland	129	Hong Kong	33
Italy	228	Czech Republic	126	Netherlands	33
Ukraine	213	Australia	116	Fed Rep Ger	32
South Korea	206	Finland	115	Sweden	32

4.2. ISI/Web of Science: Brazilian results

As shown in Table 4, there are 54 Brazilian publications listed in the ISI/Web of Science database. All the documents are articles. The first Brazilian publications occurred in 1995. Figure 5 shows the Brazilian publications per year from 1995 to 2007. The evolution of Brazilian publications per year has increased in the last years. However, if compared with the number of publications of others countries as Japan, USA and China, the Brazilian publications are quantitatively insignificant.

Figure 5. Evolution of number of Brazilian publications per year on SMAs from 1995 to 2007.

The subject categories of Brazilian publications are similar to international results presented in Table 2. *Materials Science, Multidisciplinary* (18), *Mechanics* (10), *Physics, Multidisciplinary* (9), and *Nanoscience & Nanotechnology* (8) are the principal Brazilian results found. Also there is a relative similarity considering the source titles. The two source titles with larger amount of Brazilian papers are: *Journal de Physique IV* (8) and *Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing* (7).

Considering the author's institutions, it is possible to identify that there are publications developed with foreign partnerships. In term of the language used in the articles, 52 are in English, 1 in German and 1 in Portuguese. The institutions that have, at least, 4 publications are listed in Table 5. Figure 6 shows the respective countries of partnership with the Brazilian authors.

Table 5. Institutions

Institutions	Total	Institutions	Total	Institutions	Total	Institutions	Total
UFRJ	11	UNICAMP	8	UFPB	6	UFSC	4
IME	8	CEFET/RJ	7	UFMG	5	UNESP	4

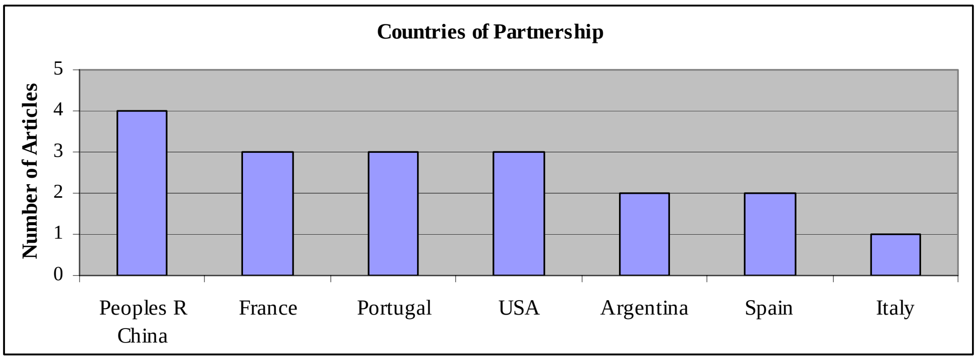


Figure 6. Countries of partnership

Figure 7 shows a graphic with the number the authors per article. It can be observed that almost all the papers were developed in partnerships with others researchers.

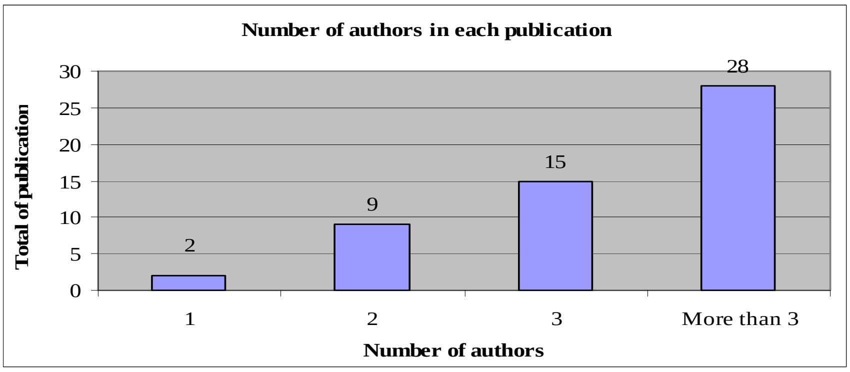


Figure 7. Number of authors per article

Finally, Fig. 8 presents the top authors of Brazilian publication on SMAs. The presented data only considers the authors with, at least, 3 publications in the topic search adopted in Web of Science database.

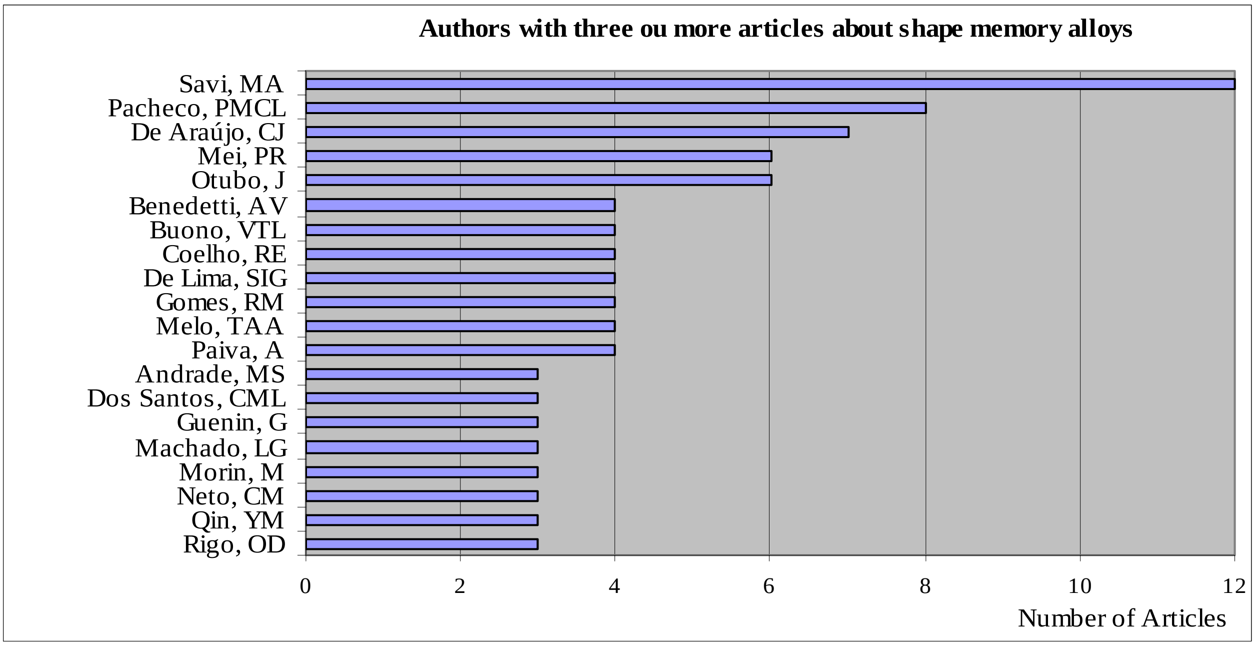


Figure 8. Top authors

4.3. Derwent Innovations Index: results

In the Derwent Innovations Index database 5,642 results were found for the topic search TS = ("shape memory alloy"). Figure 9 shows the number of patent deposits per year from 1963 to 2007. The first patent was deposited in 1977 and the second one in 1979. Since the beginning of the 80's, the number of deposits per year maintains a rising rate until a peak occurs in 1990 and 1991, reaching more than 600 deposits per year. After that peak, the number of deposits per year returns to the previous levels maintaining a positive rising rate. The peak can be the result of a legislation change in some countries. In 2007 the data colleted until April 10th shows 68 patent documents deposited. The presented data indicate that "shape memory alloy" is a recent theme and an emerging technology.

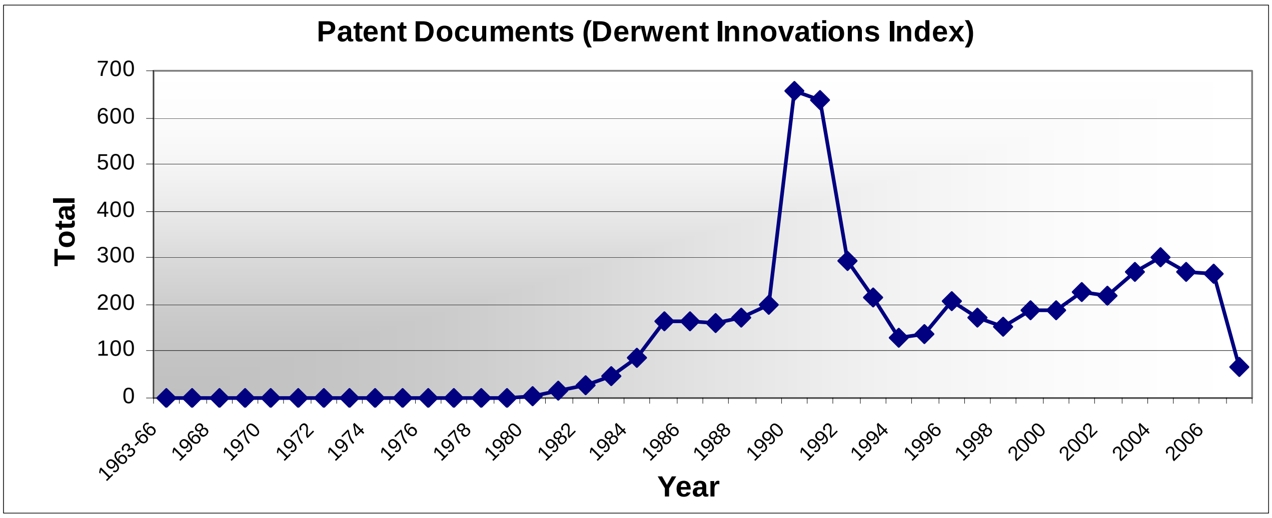


Figure 9. Total number of patents deposits per year from 1963 to 2007 in DII.

The top assignee names (owner of patent rights) are NEC Corp with 194 patents deposited and Toshiba KK with 154. Table 6 shows the fourteen top assignee names. These results show which firms are investing in shape memory alloy technology.

Table 6. Ranking of Assignee Names – DII

Assignee Names	Number of patents	Assignee Names	Number of patents
NEC CORP	194	FUJITSU LTD	100
TOSHIBA KK	154	MATSUSHITA ELECTRIC WORKS LTD	92
MATSUSHITA ELEC IND CO LTD	138	SONY CORP	62
HITACHI LTD	134	CANON KK	59
FURUKAWA ELECTRIC CO LTD	125	OLYMPUS OPTICAL CO LTD	57
MITSUBISHI DENKI KK	120	DAIDO TOKUSHUKO KK	56
TOKIN CORP	113	SHARP KK	54

Table 7 presents the ranking of the IPC code of the patent documents found in DII. Table 8 shows the description of the sections, classes, subclasses, groups and subgroups of the ten principal results shown in Table 7.

Table 7. Ranking of IPC code - DII

IPC	Total	IPC	Total	IPC	Total	IPC	Total
C22C-019/03	463	C22F-001/00	109	A61M-025/00	64	A61B-001/00	52
F03G-007/06	259	H01H-037/32	107	H02N-010/00	61	C22C-001/00	51
C22F-001/10	168	A61M-029/00	85	C22F-001/08	60	G01K-011/00	51
A61F-002/06	121	C22K-001/00	84	A61B-017/00	54	H01L-023/50	50
C22C-014/00	118	F16K-031/70	81	C22C-038/00	54		

Table 8. Description of IPC codes present in the principal results of Table 7

Section	Class	Subclass	Group	Subgroup
C Chemistry; metallurgy	22 Metallurgy; ferrous or non-ferrous alloys; treatment of alloys or non-ferrous metals	C Alloys	019 Based on nickel or cobalt	03 Based on nickel
			014 Based on titanium	00
			038 Ferrous alloys, e.g. Steel alloys	00
			001 Making alloys	00
		F Changing the physical structure of non-ferrous metals or non-ferrous alloys	001 Changing the physical structure of non-ferrous metals or alloys by heat treatment or by hot or cold working	10 Of nickel or cobalt or alloys based thereon
				00
		K Indexing scheme associated with subclasses C21D, C22C or C22fF, relating to changing the physical characteristics of alloys	001 Changing the physical structure of alloys resulting in shape memory effect; Processes for stabilising or changing such effect; Alloys having shape memory characteristics	00*
F Mechanical engineering; lighting; heating; weapons; blasting	03 Machines or engines for liquids wind, spring, or weight motors; producing mechanical power or a reactive propulsive thrust, not otherwise provided for	G Spring, weight, inertia, or like motors; mechanical-power-producing devices or mechanisms, not otherwise provided for or using energy sources not otherwise provided for	007 Mechanical-power-producing mechanisms, not otherwise provided for or using energy sources not otherwise provided for	06 Using expansion or contraction of bodies due to heating, cooling, moistening, drying, or the like
	16 Engineering elements or units; general measures for producing and maintaining effective functioning of machines or installations; thermal insulation in general	K Valves; taps; cocks; actuating-floats; devices for venting or aerating	031 Operating means; Releasing devices	70 Mechanically actuated, e.g. by a bimetallic strip
A Human necessities	61 Medical or veterinary science; hygiene	F Filters implantable into blood vessels; prostheses; devices providing patency to, or preventing collapsing of, tubular structures of the body, e.g. Stents; orthopaedic, nursing or contraceptive devices; fomentation; treatment or protection of eyes or ears; bandages, dressings or absorbent pads; first-aid kits	002 Filters implantable into blood vessels; Prostheses, i.e. Artificial substitutes or replacements for parts of the body; Appliances for connecting them with the body; Devices providing patency to, or preventing collapsing of, tubular structures of the body, e.g. Stents	06* Blood vessels
		M Devices for introducing media into, or onto, the body; devices for transducing body media or for taking media from the; devices for producing or ending sleep or stupor	029 Dilators with or without means for introducing media, e.g. remedies	00
H Electricity	01 Basic electric elements	H Electric switches; relays; selectors; emergency protective devices	037 Thermally-actuated switches	32 Thermally-sensitive members

(*) Previous edition

5. CONCLUSION

This exploratory and quantitative study had the main objective of stimulate the dissemination of scientific and technical information trough the use of databases – Web of Science and Derwent Innovations Index – available in the Internet. Scientific publications and patent documents contain important data that can be used to support management decisions in R&D.

The theme of the search was shape memory alloys. The research showed that it's an emerging technology. The data collected shows an expressive increase in the number of publications about SMAs since the 90's. The study developed showed that *materials science* (multidisciplinary) and *metallurgy & metallurgical engineering* are the principal subject categories followed by nanoscience & nanotechnology. Japan, USA and China are the three countries with the biggest number of publications and that Brazil is in 23rd position of ranking with 54 publications.

An increase in the number of Brazilian publications is observed in the last years. UFRJ, IME, UNICAMP, CEFET/RJ and UFPB are the Brazilian institutions that have the larger amount of the articles on SMAs. It was also possible to identify that some Brazilian publications were developed with foreign partnerships and that almost the totality of the papers was developed in partnerships with others researchers.

Also it was identified that NEC Corp, Toshiba KK, Matsushita Elec Ind Co Ltd and Hitachi Ltd are the principal assignee names of this technology and that the large number of deposits of patent is associated to alloys based on nickel.

It’s important to be mentioned that the information presented in this paper is based on a preliminary search for the subject shape memory alloy. To obtain a complete assessment on the subject it is necessary to develop a larger search program, that includes new searches with others topics, combinations and parameters related to shape memory alloy, to permit the retrieval of others documents in these databases.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Birman, V., 1997, “Review of mechanics of shape memory alloy structures”, *Applied Mechanics Review*, v.50, pp.629-645.

Chang-jun,Q., Pei-sun, M. e Qin, Y., 2004. “A prototype micro-wheeled-robot using SMA actuator“, *Sensors and Actuators*, A 113, pp.94–99.

Campanile, L.F., Keimer, R. e Breitbach, E.J., 2004. “The ‘‘Fish-mouth’’ Actuator: Design Issues and Test Results”, Journal of Intelligent Material Systems and Structures, Vol. 15, pp. 711-719.

Denoyer, K.K., Scott Erwin, R. & Rory Ninneman, R., 2000, “Advanced smart structures flight experiments for precision spacecraft”, *Acta Astronautica*, v.47, pp.389-397.

Elzey, D.M., Sofla, A.Y.N. e Wadley, H.N.G., 2005. “A shape memory-based multifunctional structural actuator panel”, *International Journal of Solids and Structures*, 42, pp.1943–1955.

Garner, L.J., Wilson, L.N., Lagoudas, D.C. and Rediniotis, O.K., 2001, “Development of a shape memory alloy actuated biomimetic vehicle”, *Smart Materials and Structures*, v.9, n.5, pp.673-683.

Hodgson, D. E., Wu, M. H. and Biermann, R. J., 1992. “Shape Memory Alloys”, *ASM Handbook*, v. 2, p. 887-902.

Kibirkstis, E., Liaudinskas, R., Pauliukaitis, D. and Vaitasius, K., 1997, “Mechanisms with shape memory alloy”, *Journal de Physique IV*, C5, pp.633-636.

La Cava, C.A.P.L., Pacheco, P.M.C.L. e Savi, M.A., 2000. “Modelagem de um Dispositivo de Pré-Carga com Memória de Forma para Juntas Flangeadas”, *CONEM 2000 – Congresso Nacional de Engenharia Mecânica*, Natal-RN, Agosto.

National Research Council, 1999. *“A Question of Balance: Private-Rights and the public Interest in Scientific and Technical Databases”*. Committee for a Study on Promoting Access to Scientific and Technical Data for the Public Interest, National Academy of Sciences, National Academies Press. 15 April 2007. <http://books.nap.edu/html>.

Machado, L.G. and Savi, M.A., 2003, “Medical applications of shape memory alloys”, Brazilian Journal of Medical and Biological Research, v.36, n.6, pp.683-691.

Pacheco, P.M.C.L. and Savi, M.A., 1997, “A non-explosive release device for aerospace applications using shape memory alloys”, *Proceedings of XIV the Brazilian Congress of Mechanical Engineering (COBEM 97 - ABCM)*, Bauru, Brazil.

Rackette, K., 2006. “Patent information and searching”. Patent Drafting Workshop, Indonesia. 12 Apr 2007, <http://www.ecap-project.org>

Rogers, C.A., 1995, “Intelligent Materials”, Scientific American, September, pp.122-127.

Shin, D.D., Mohanchandra, K. P. e Carman. G.P., 2005. “Development of hydraulic linear actuator using thin film SMA”, Sensors and Actuators A 119, pp.151–156.

Thomson, 2003. “Derwent Innovations Index”. 20 Mar 2007. <http://www.scientific.thomson.com>

van Humbeeck, J., 1999, “Non-medical applications of shape memory alloys”, *Materials Science and Engineering A*, v.273-275, pp.134-148.

Webb, G., Wilson, L., Lagoudas, D.C. and Rediniotis, O., 2000, “Adaptive control of shape memory alloy actuators for underwater biomimetic applications”, *AIAA Journal*, v.38, n.2, pp. 325-334.

Williams, K., Chiu, G. and Bernhard, R., 2002, “Adaptive-passive absorbers using shape-memory alloys”, *Journal of Sound and Vibration*, v.249, n.5, pp.835-848.

WIPO, 2007. “International Patent Classification”. 25 Mar 2007. <http://www.wipo.int/classifications>

Zhang, X.D., Rogers, C.A. & Liang, C., 1991, “Modeling of Two-Way Shape Memory Effect”, *ASME - Smart Structures and Materials*, v.24, pp.79-90.

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