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An Artistic Approach to Thermal Spray

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Abstract. "Art is everywhere" to quote Ben, a renowned French contemporary artist. However, there are some areas in which art is more prevalent. Thermal spray is one of them, as this presentation seeks to demonstrate. For this, each of the arts (according to their official classification) is shown to correspond to a specific key point of the thermal spray process for coating: e.g., coating build-up, additive manufacturing, deposition onto brittle and/or temperature sensitive materials (glass, wood, fabrics, polymers), powder optimization, and adhesion. Both modeling and experimental aspects are discussed, focusing on the study of particle-to-particle or particle-to-substrate interfaces, shock phenomena and advanced investigation techniques such as X-ray microtomography or high-speed instrumentation. Plasma spray and cold spray provide the relevant examples that this contribution elaborates. They relate to different industrial sectors such as aircraft-aerospace, luxury, biomedical and the automotive industry. Beyond anecdotal evidence, the discussion aims to show that an artistic approach to thermal spray does help to understand better this powerful coating process.

Introduction

, i.e. "Art is everywhere" in English, to quote Ben, who could have added "…including in the thermal spray area" since all art facets are exhibited in thermal spray. These will be discussed in this article, based on the classification of the arts, which had been proposed by Hegel [1], in the 19th century, i.e.: architecture (the 1st art), sculpture (the 2nd art), painting and drawing (the 3rd art), music (the 4th art), literature (the 5th art), performing arts (the 6th art), cinema (the 7th art), photography (the 8th art), comics (the 9th art), and fashion arts. The latter was selected in a still open list of disciplines which claim to be considered as the 10th art.

Even though thermal spray is not yet considered as a full-fledged art, this process can be stated to be relevant to arts, according to many criteria. A first evidence of this was given by Salvador Dali who sprayed nails with a gun to coat the hard cover of his "Saint Jean Apocalypse" book in its unique (in every sense of the word) edition of 1959 [2]. For this mere reason, Dali can be recognized as a pioneer in thermal spray, as M.U. Shoop [3] et A. Papyrin [4] who are commonly said to be the inventors of thermal spray and cold spray respectively. For all of them, the invention of thermal spray resulted from serendipity due to observation of the impact of projectiles onto a substrate. In the 3 cases, the background was rather chaotic, due to the First World War, the (aptly-named) cold war and the Apocalypse for Shoop, Papyrin and Dali respectively.

Numerous examples in this article should show that thermal spray can play a significant role on the rapprochement between art and science. In the field of materials, this rapprochement is remarkable, as ascertained by the content of materials conferences in which specific sessions devoted to arts have been included since the year 2000, e.g. at the 18th international conference on "Surface Modification Technologies" (SMT18) in Paris [5]. Moreover, more and more exhibitions promote the dialog between art and materials. To remain in the Parisian area, one may mention the recent "E=mc215" exhibition at the Arts & Métiers Museum /Paris, in Jan.-Feb. 2015 [6].

Thermal Spray and Architecture (The 1st Art)

Coating build-up meets the basic principle of thermal spray through the impinging of "elementary bricks" which are made of sprayed particles. In its very essence, thermal spray is architecture which leads the arts family, as a "tête de l'art" to use an untranslatable play on words in French. Coating build-up can look as amazing as dry stone masonry, which utilizes neither mortar nor any other binder. One may wonder how such a construction work can hold together well. One will say it is due to a "cold welding" effect, when talking about cold spray while one will merely refer to the Roman genius when talking about the Hadrian's Wall, which is an exemplary masterpiece of dry stone work [7]. Anyway, there is lack of explanations. To explain these miracles, one has to refer to the build-up process basically, i.e. that which uses sprayed particles and that which uses dry stones, for cold spray and the Hadrian's Wall erection respectively. For the Hadrian's Wall, the build-up process resulted from empiricism. However, in cold spray, the process can be for a good part elucidated from numerical simulation.

Very recent advances in simulation of the cold spray coating process come from the combination of finite element (FE) analysis of particle impact with morphological modeling of their coating build-up. The basic principle is to use the real deformation of all the particles, given by FE analysis, as an input in the morphological model, based on the use of statistics. The most advanced FE analysis is in three dimensions (3D) and relates to irregular particles, using Abaqus® (Fig. 1) [8], in contrast with conventional simulations which are 2-dimensional only and/or involving spherical particles only.

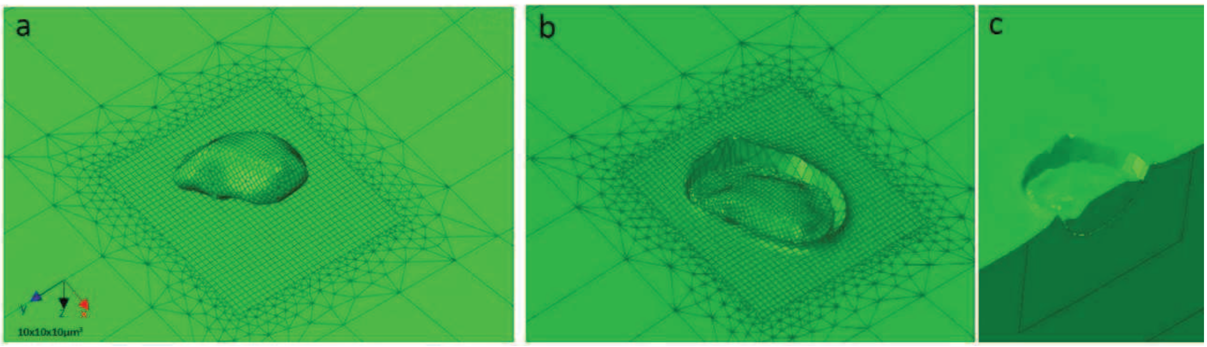

Fig. 1: Two-dimensional FE simulation of an irregular cold-sprayed Ta particle onto Cu, a) Top view just prior to the impact, b) and c) Top and cross-sectional views at the end of the impact.

Subsequent simulation of the coating build-up can therefore be applied through iterative modeling, starting from FE results. The particles are deposited one after the other, in a number which can be unlimited. Physical bases are thus involved, which differs from previous morphological models, which were, however, already well advanced, e.g. purely statistical lattice-gas models as those developed for plasma spray simulation [9]. This new type of simulation involves complete displacement fields for the sprayed particles, using the Delaunay's triangulation method, which results in a spatial paving when assigning each point to a triangle. Two approaches to the build-up morphology can be set up. One is discrete and the other one is vectorial. This type of simulation is currently in progress and is expected to lead to a global simulation of cold spray coating build-up soon [10]. Already-obtained results, even though they are 2D results only which need to be improved, are quite promising (Fig. 2a). Since the bases for calculations are now established, the in-progress research work should complement well in the near future results from advanced phenomenological models, in which however physical criteria were not involved (Fig. 2b).

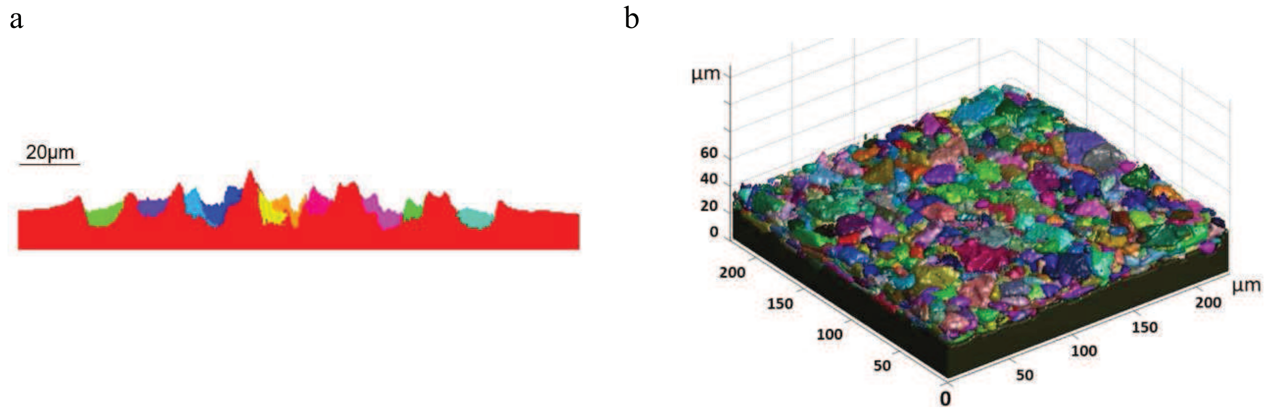

Fig. 2: Coating build-up simulation of cold-sprayed Ta onto Cu, Cross-sectional view using a 2D discrete approach, b) 3D perspective view in a phenomenological approach, after [11].

Thermal Spray and Sculpture (The 2nd Art)

Formerly, knowledge in architecture could bring much to sculpture and the reverse, as evidenced by the so-called "total artists" such as Le Bernin, Pisano, Raphaël or Brunelleschi who excelled in both of these arts. In present times, things are rather different. However, thermal spray can provide with an opportunity to renew the tradition through its capability to direct free-standing parts directly. Thermal spray additive manufacturing can therefore be seen as art, all the more because these parts are works of arts.

Following plasma spray-forming, which has been used for many years [12], cold spray now begins to show the tip of its nozzle to appear as a powerful additive manufacturing process, in the wake of the popular laser additive manufacturing [13]. First results by General Electric (Fig. 3) go in that direction [14]. They show the progress made since the pioneering works by J. Pattison et al., in 2007 [15] but also that to be done in the future. The latter is due to the fact that no research work has not been yet published dealing with properties of the as-directly sprayed parts and/or the feasibility of achieving given shapes. However, the already-described results in the previous section ("Architecture") are a good basis for development in this field.

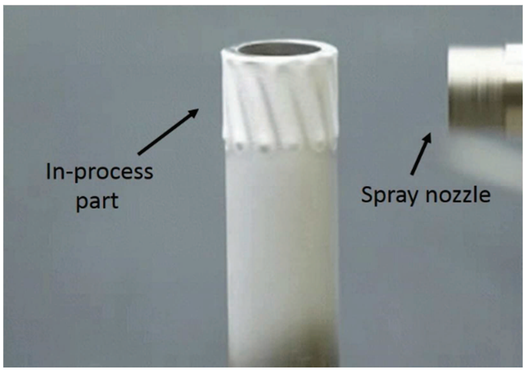

Fig. 3: Direct additive manufacturing of a helical gear (outer diameter of about 3.5cm), after [14].

Thermal Spray and Painting/Drawing (The 3rd Art)

A total artist, in the conventional sense of the word, whose famous examples were given in the previous section, generally adds a talent for painting to those for architecture and sculpture. Thermal spray can help in that way due to some recent applications which exploit its high process flexibility. For example, glass can be coated to result in graphics which can be compared to a conventional stained-glass artist work. Useless to say that this can open a nice outlook for artistic and professional changes in this field.

In this specific thermal spray work the challenge comes from the brittleness of glass, which is very sensitive to thermal and mechanical shocks. However, a good control of the spraying conditions allows to deposit metals onto conventional glasses. At the early stage of development, thermal spray was limited to the deposition of straight and homogeneous conductive paths at the glass surface, e.g. for solar cells or electrically heated panes [16, 17]. Nowadays, spray coating of glass relates more to craftwork, due to capability of drawing and shadowing. A thermal sprayer shows a high potential to compete with a stained-glass artist or a stencilist, all the more as he can deposit metals as well as colored glasses. Compared to the processing of a stained glass, there is no need for lead or copper strips to bond glass elementary pieces.

Logos such as that of the French materials association “Matériaupôle” (www.materiaupole.org), could thus be obtained using plasma spray of aluminum onto conventional float glass (Fig. 4).

a b

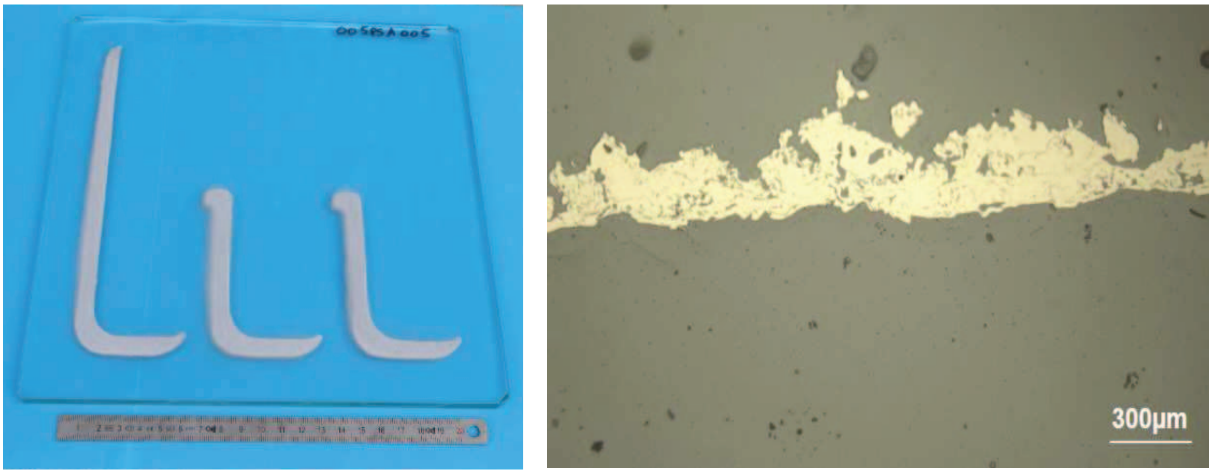

Fig. 4: Plasma spray drawing of Al onto glass, a) Optical top view of the as-sprayed “Matériaupôle” logo, Optical cross-sectional image of the corresponding Al coating onto float glass (topped with embedding resin).

Thermal spray was carried out using masking. The mask had been designed to ensure gradual shading of the outlines for better esthetics (Fig. 4a). Coating bond strength, microstructure and properties were good enough for the aimed application, i.e. signage (Fig. 4b).

Plasma spray studies of colored glass is currently under progress. They deal with the determining of spray conditions with which there is no glass depigmentation. For this, plasma gases must prevent any reduction of the colored pigments in the starting glass powders. In the plasma gas mixture, hydrogen cannot therefore be used, unlike other gases such as argon or helium. Operating conditions will be described in an article in preparation. Coating roughness and, to the second order, color and translucency can be changed due to post-spray annealing (Fig.5), which can lead to attractive artistic effects.

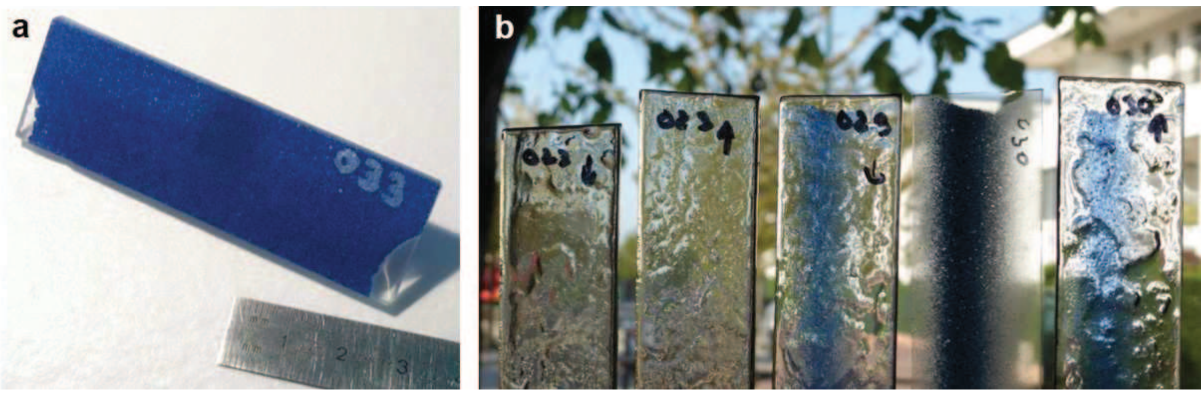

Fig. 5: Coating of float glass specimens with glass, a) As-sprayed plain blue, b) Pale orange, yellow, blue1, black and blue2 (from left to right) after annealing.

Thermal spray-coated glass can also be envisaged for art & design, decoration, marking and/or packaging. Coppering and ceramization (with alumina) of perfume bottles were carried out recently, as presented at THERMEC'2016 in Graz, which however cannot be shown in this article.

Thermal Spray, Music and Performing Arts (The 4th and 6th Arts)

Thermal spray of glass and onto glass could also be related to music (the 4th art) in addition to drawing (as in the previous section) in so far as this process would be suitable for coating musical instruments. This could lead to new sounds from resulting acoustic modification. A prominent example is that of the Dobro guitar, which was immortalized by Taj Mahal or Ry Cooder et al., in particular. Even though this can be useful to burn up the stage as in performing arts (the 6th art), the art of thermal spray in that case is not to burn the wood of which the instrument is made. Provided that these conditions are met, metallization and ceramization of instruments for example, are no more considered as heretical acts by violin makers. However, one will avoid using a Stradivarius for that.

The making of wooden instrument presently opens to thermal spray, as cabinetmaking can do. For the latter thermal spray is expected for better functionalization and/or anesthetization. If spray conditions are adapted to the type of wood, both ceramic and metal coatings can be deposited successfully. This application is very innovative, even though the substrate material cannot be considered strictly speaking as a high-tech material (sometimes at best a high-teak material). Recent plasma spray tests showed the feasibility of achieving thickness-controled, uniform or discontinuous (speckled) coatings which were made of copper, aluminum, and alumina, for example (Fig. 6). Studies involved various species of woods such as olive wood, pearwood, and ebony. No surface preparation, e.g. grit blasting, had to be applied. The coating-substrate adhesion mechanism was exhibited to be mechanical anchoring. The first sprayed liquid droplets are embedded in the wood, surrounding the wood fibers when solidifying, which provokes a high pegging effect (Fig. 6b). Plasma spray conditions were optimized to prevent any detrimental heat damage. Two major parameters must be pointed out, i.e. the moisture content and hardness of the wood, which incidentally are not independent actually The first parameter is all the lower as the wood is old. Hardness depends on the growth speed of the wood, i.e. low in Winter (winterwood) or high in Summer (summerwood) [18]. Moreover, a species of wood which can desorb water and/or oil, e.g. an oily wood such as ebony, might require some heat treatment prior to spray to promote adhesion.

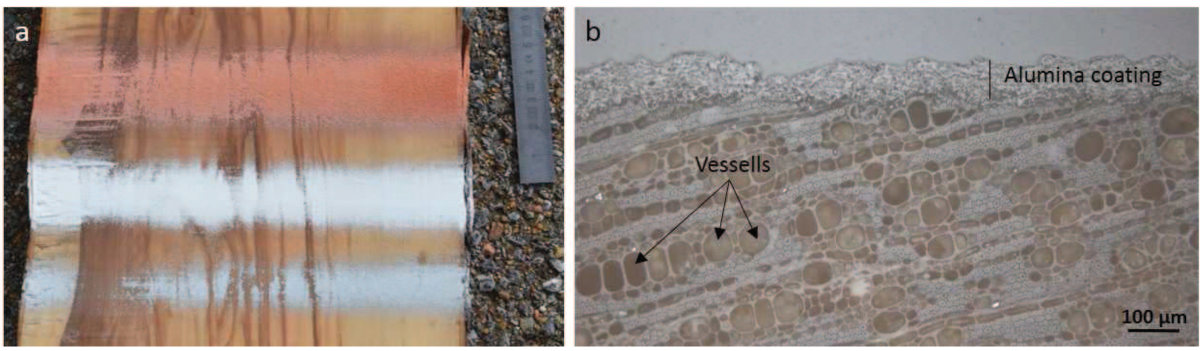

Fig. 6: Optical images of an olive wood board, a) Top view of plasma-sprayed beads made of (bottom to left) aluminum, alumina, and copper, b) Cross-sectional view of alumina coating, in its thickest part, parallel to the wood vein.

A slow wood growth results in a low-porosity hard wood with highly tightened fibers. In contrast, a rapid growth increases the number of pores, which decreases hardness. This growth variation as a function of seasons leads to dark and bright veins respectively (Fig. 6a). These veins show a significant difference in hardness, i.e. about $17HV_{20}$ typically for dark veins when compared to much lower than $8HV_{20}$ (out of range measurement) for bright veins. These hardness measurements were performed using Vickers indentation since Monnin measurements, which are conventional for application to wooden materials, could not be done. This difference in vein hardness causes different and deferred anchoring mechanisms for sprayed particles at the surface of the wood. This result can be nicely exploited to highlight the veins of the wood (Fig. 6a). Various effects can be obtained depending on the coating material and thickness. This aestheticization is appealing for luxury cabinetmaking or for more humble wood craftsmen. In addition to vein highlighting, thermal spray can be beneficial for the revealing of the curly figure of the wood (when possibly existing). For example, a medium hard wood like pearwood, can therefore be very suitable for such esthetic surface treatment (Fig. 7).

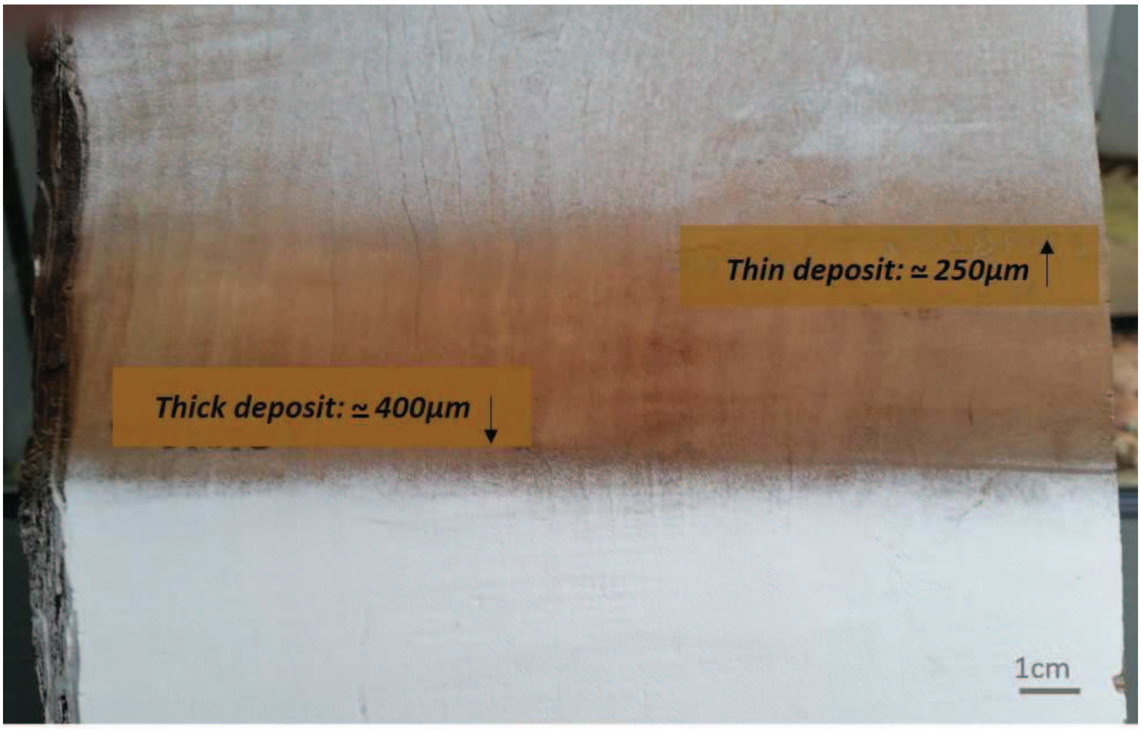

Fig. 7: Optical top view of an alumina-coated curly figured pearwood board. Influence of coating hardness on the aestheticization of the curly figure: 250µm-thick alumina (at the top) and 400 µm-thick alumina (at the bottom).

The curly figure in a wood is a figure pattern which looks like ripples. Its origin has not yet been established though it is probably genetic. A curl is a structure defect in the countergrain of the wood. The corresponding curly figure is revealed from light incidence effects related to the orientation of the wood fibers (Fig. 7 and Fig. 8), which, by definition, is not constant in that case. Aestheticize the curly figure of the wood through thermal spray means to promote the ripple effect due to the presence of a coating which can be shallow. The corresponding wavy surface can be evidenced by 3D profilometry (Fig. 8).

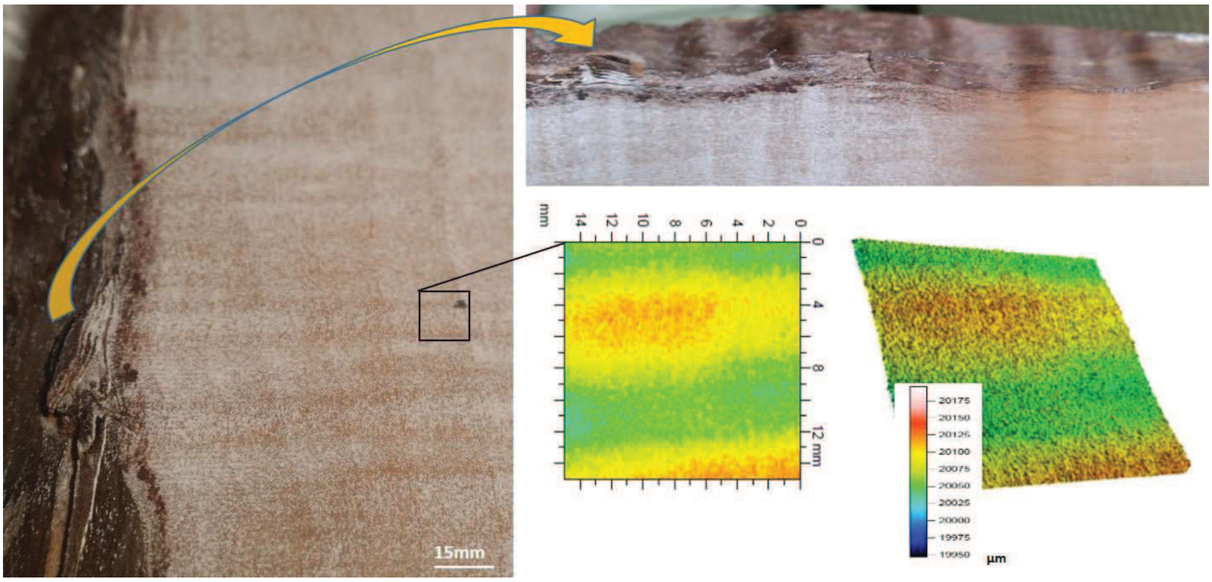

Fig. 8: Optical images (2 orientations) of a curly figured pearwood board surface after shallow deposition of plasma-sprayed alumina, and corresponding (raw and upright) topographical 3D images.

Thermal Spray and Cinema (the 7th Art)

In thermal spray, as can be expected, the starting powder plays a prominent role, and even the first role when cold spray is involved. The relation is therefore easy to establish between cold spray and the 7th art since distribution is of major concern in both cases. The author of this article could be told that it is a bit easy write that. However, it would have been easier to say that cinema is the art of projection. If a remake of the Oscar-winning French movie "The Artist" (in French in the text) happens to be produced, one may assume that the powder would be the featured star. This would be all the more true since "The Artist" is a silent movie in which "one would never make the powder talk", according a French proverb which means that people has to remain always quiet. One could even extend the analogy. The film tells the story of a silent movie star who does not want to develop professionally and refuses the talking cinema. The same could be said regarding powders for cold spray. Up to now, (almost) only conventional powders, which were formerly developed for conventional thermal spray, i.e. plasma and flame spray, were used in cold spray, in a finer grain size at best. Now, it is time to think about progressing (as Valentin/Dujardin has to do at the end of the movie) with the development of cold spray tailored powders. This, however, requires to know the most suitable characteristics.

Morphological Characteristics of Powders. The most advanced development covers studies of the morphology of the particles which form the starting batch to be cold sprayed. It is known that morphology mainly governs particle deformation at the impact, consequently the resulting adhesion to the substrate. Latest results showed that the various particle morphologies could be classified in a complete library to result in a thorough characterization of the powder batch. Once this classification has been established, morphologies can be used as inputs in coating build-up models to lead to a general simulation of deposition, as already described in the "1st Art" section

X-ray MicroTomography (XMT) is a powerful tool for access to a description of spray particles. Tens of thousands of particles can be XMT-imaged in 3 dimensions. These can result in a library due to the use of specific algorithms as those which were developed in the so-called SMIL, i.e. "Simple Morphological Image Libraries » [8, 10], for the processing of the XMT images with separation of aggregates. A classification in the library can involve a series of morphological parameters for quantification of all objects (particles): i.e., the volume, surface, surface/volume ratio, radius, equivalent radius, sphericity, imbrication, principal moments of inertia, and safe box dimensions. The 2 latter parameters come from the tensor of inertia, I, which involves the weight and coordinates of the points (Eq. 1)

$$I = \begin{pmatrix} \sum_i m_i\left(y_i^2+z_i^2\right) & -\sum_i m_i x_i y_i & -\sum_i m_i x_i z_i \\ -\sum_i m_i x_i y_i & \sum_i m_i\left(x_i^2+z_i^2\right) & -\sum_i m_i y_i z_i \\ -\sum_i m_i x_i z_i & -\sum_i m_i y_i z_i & \sum_i m_i\left(x_i^2+y_i^2\right) \end{pmatrix} \tag{1}$$

and the principal axes of inertia. The principal axes of inertia, λ_1 and λ_2, give a representation of the moments of inertia, which can lead to the location of every object as a function of its shape, i.e. that of a needle, a disc or a sphere (Fig. 9).

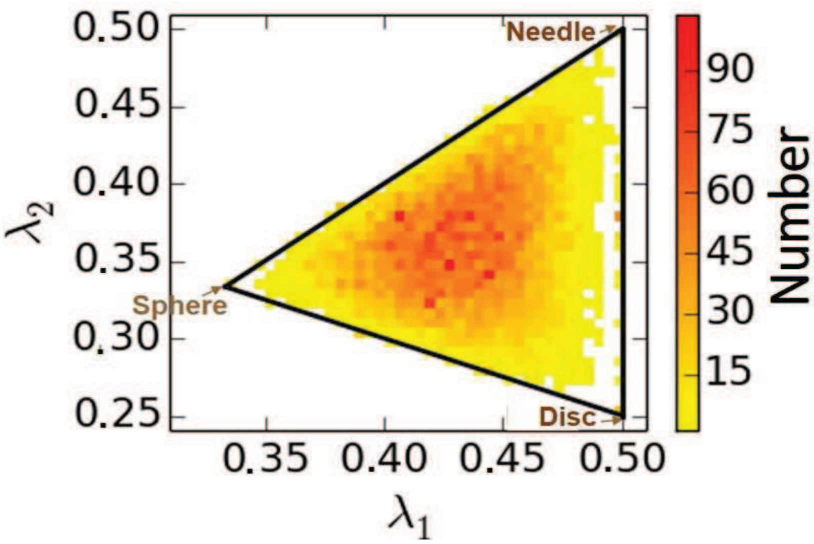

Fig. 9: Particle shape in the library as a function of the principal moments of inertia, (λ_1, λ_2).

Subsequent sorting of the particles results from a correlation between measurements and analyses of the main components. In a final stage, a cluster analysis for data partitioning, using the so-called "K-means" method for example, leads to particle classification. The example of a tantalum batch powder is given in Fig. 10. In this example, about 18,000 particles were characterized and shared into 7 morphology classes. As previously-said, the XMT (X-ray MicroTomography) images can be used as inputs in a 3D numerical simulation of coating-build-up. The comparison between the visual perceptions of the various shapes shows that the developed particle classification tool is very discriminating. Some differences which are not easy to detect visually are exhibited through the systematic and numerical technique which was used.

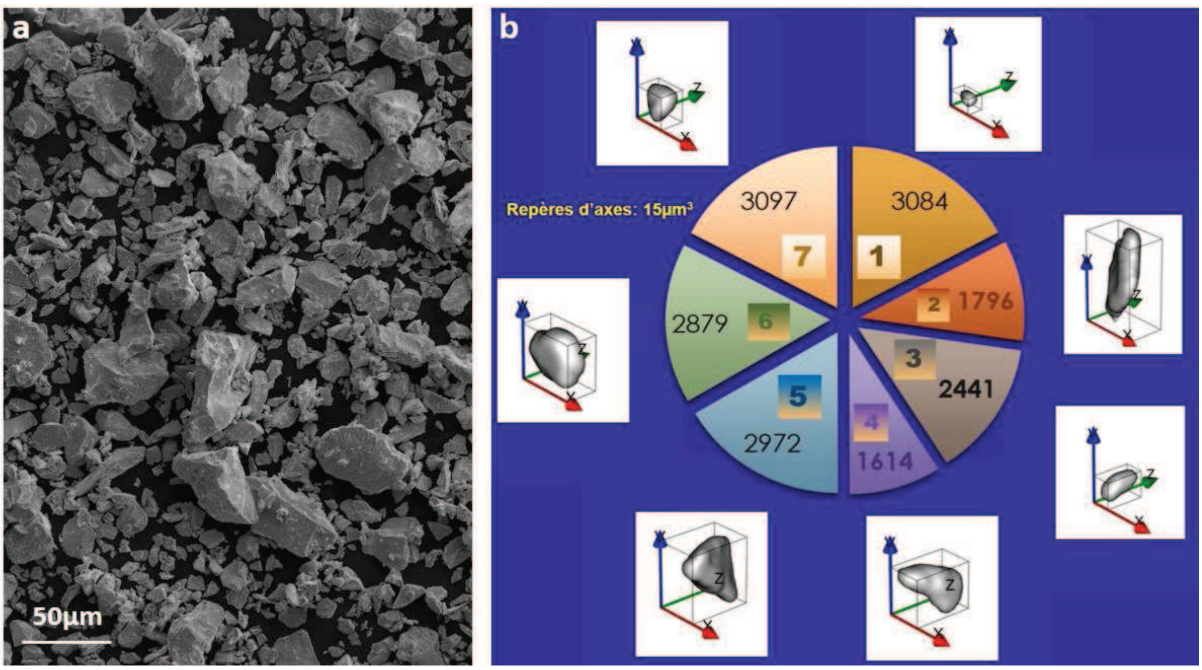

Fig. 10: Particle classification in a powder batch of Ta, a) SEM image of the powder, b) Pie chart made of 7 particle classes (with the number of particles par class and corresponding XMT images).

Metallurgical Characteristics of Powders. In addition to morphological characteristics (see previous section), metallurgical characteristics has to be known for suitable powder use. This knowledge is especially requested in cold spray, due to the influence of powder metallurgical features on the final coating microstructure. There is a strong heredity from powder to coating since all particles remain at solid state (except for very local parts sometimes) during the whole process. In the selection of a powder for cold spray, one should consider the metallurgical structure of the particles, even though it is not usual actually. That issue is addressed in a specific article by the author, to which the reader may refer [11]. This article will therefore give only an illustration of metallurgical transformation of the cold-sprayed particle at the impact with the substrate (Fig. 11).

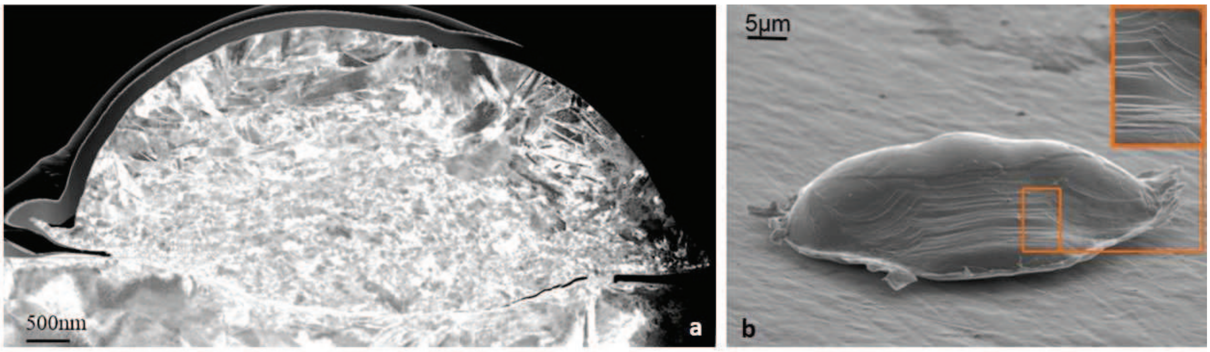

Fig.11 : Images of a cold-sprayed Ti particle after impacting on a Ti-6Al-4V substrate, a) TEM image of a cross-sectional thin foil of a splat, b) SEM image of a Manta ray-like or Dart Vader-faced splat.

The particle microstructure can be submitted to several mechanisms, i.e., dynamic recrystallization, twinning, restoration, material jetting and transient melting with possibly amorphization depending on materials (Fig. 11a), and slip band formation. The latter can be seen at the splat surface (Fig. 11b).

Thermal Spray, Photography (the 8th Art) and Comics (the 9th Art)

Images such as those in Fig.11 that some might consider as artistic, consists of a research tool for developing thermal spray and related knowledge. It is in that way that the 8th art might be evoked. These types of images mainly relate to fast imaging due to the dynamic nature of thermal spray processing. Two examples can be featured, i.e. suspension plasma spray (SPS) the rise of which is undeniable [19] and cold laser shock spray (CLASS), the basis of which was laid in 2010 [20]. SPS is particularly suitable for illustration of the interest of in situ observation using fast imaging techniques when applied to a thermal spray technology. This type of observation contributed (and still contributes) greatly to advances in processes such as plasma spray. In SPS, the injection of the suspension can be monitored continuously for process control and optimization (Fig. 12).

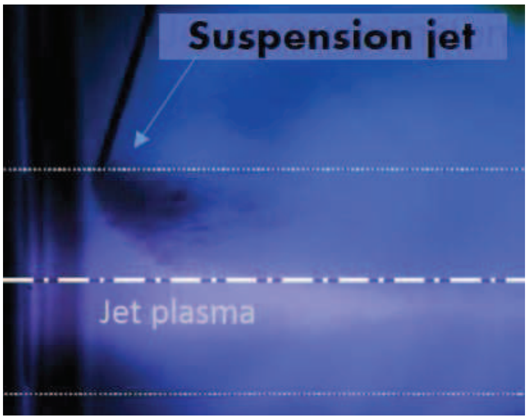

Fig.12: Fast camera image of the injection of a liquid suspension in a plasma jet in Suspension Plasma Spraying (SPS), after [19].

The example of Cold LAser Shock Spray (CLASS) features the role of shadowgraphy for the imaging of a spray of particles due to a laser shock (Fig. 13) [20]. A laser shock of a few ns typically can provoke a sort of mechanical atomization of the substrate due to spallation phenomena. The sprayed particles are made of spalls which correspond to splats when the substrate is made of a thermally-sprayed material. In that case, CLASS is a sort of re-spraying process, which is rather similar to cold spray in so far as particle velocity due to laser shock can be compared to that obtained in conventional cold spray. Accurate measurements of particle velocities result from the study of a sequence of shadowgraphs.

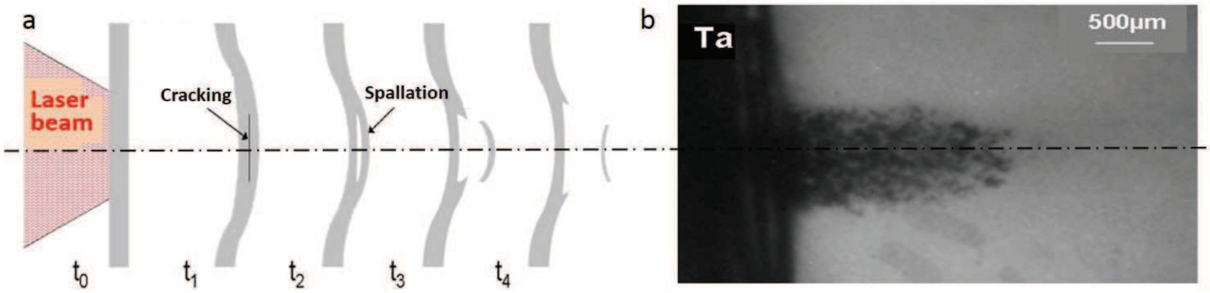

Fig.13: Cold LAser Shock Spray (CLASS) of tantalum, a) Schematic illustration, b) Shadowgraph of in-flight particles.

The use of advanced imaging techniques is crucial for the development of thermal spray. However, less advanced images, as can be seen in comic strips, can also be helpful, to express some fundamentals of thermal spray. One may refer to "llama" spray which represents well what plasma spray can be, beyond the homophony (Fig. 14). The 9th art can also therefore meet thermal spray.

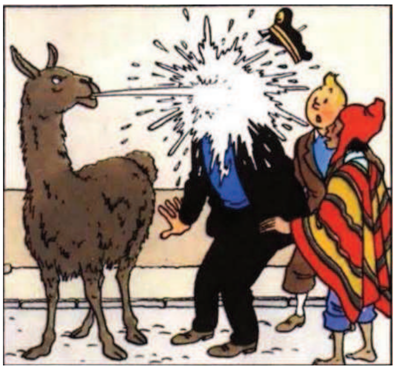

Fig.14: Llama spray as an illustration of plasma spray, after Hergé in 1949, [21].

Thermal Spray and Fashion Arts (the 10th Art)

Meeting the 10th art for thermal spray can provoke questioning in so far as several disciplines claim to be this 10th art. The haute couture and cuisine hold the rope for designation, especially in France as can be easily guessed. These would be termed as fashion and culinary arts in that instance. Even though one is tempted to say that thermal spray is often similar to cooking, it was preferred that this part of the article be devoted to fashion arts. The reason rests on the feasibility of coating fabrics using thermal spray. A recent and advanced example is that of haute couture silk. Up to now, there was very little only on the coating of fabrics by thermal spray. To the knowledge of the authors, one paper only dealt with this topic [22], which moreover did not relate to silk.

Thermal spray capability of coating thermosensitive materials has long been recognized. The example of WC-Co-coated paper is well known, despite a burning temperature of 451 °F only for paper, as showed by Bradbury and Truffaut (to stay in the artistic planet). Till now, severe cooling (e.g. cryogenic) systems or moderate temperature processes (e.g. arc spray) had to be employed for this. However, their use can be avoided, provided that operating conditions can be controled. A striking example is that of plasma spray of ceramics onto haute couture silk, in which a high-temperature process and a low-temperature and delicate material were therefore involved (Fig. 15). "Coated coats" can thus be envisaged.

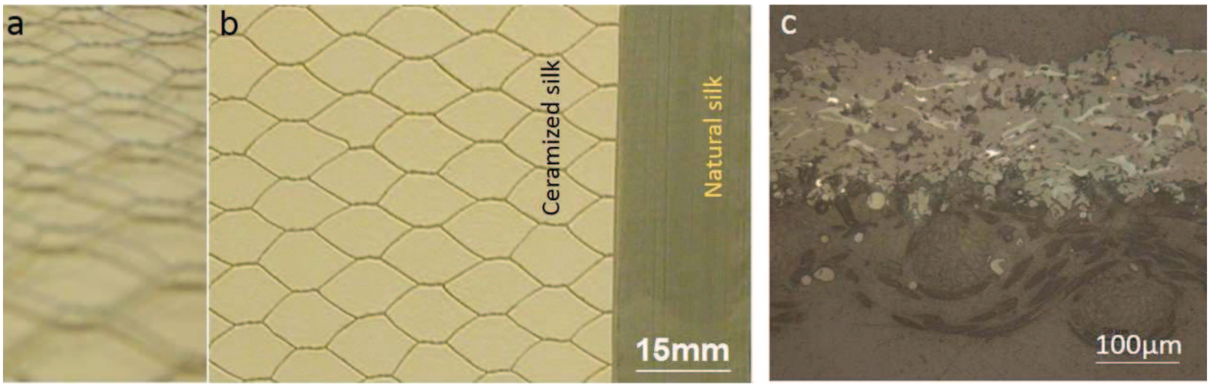

Fig.15: Hydroxyapatite (HA) coating of haute couture silk, a) Optical perspective view of the stencil grid, b) Optical top view of stencilled HA coating (left), c) Optical cross-sectional view of HA-coated silk.

High-quality hydroxyapatite (HA) coating could be obtained (therefore without any cryogenic assistance). Coating-substrate bond strength resulted from mechanical anchoring of the ceramic particles which clamped the silk fibers at the surface, with no detrimental thermal damage (Fig. 15c). To give the coated material a certain suppleness, thermal spray could be applied though a stencil which acted as a mask. This mask can be a grid to result in a fish scale pattern (with no overlaps) which are mutually-articulated (Fig. 15a and Fig. 15b).

HA is similar to that used for conventional coating of hip prostheses. HA composition is close to that of a bone, which promotes tissue reconstruction on the medical implant. For a stylist, an Ha-coated dress could appear as an exoskeleton to dress a (skeletal) top model.

Hot material can therefore be deposited onto thermo-sensitive substrates by thermal spray. Bright prospects can therefore be expected for the coating of thermosensitive materials such as fabrics. The rest is pure speculation, i.e. literature for some people (see subsequent section).

Thermal Spray and Literature (the 5th Art)

One may wonder where literature can be in thermal spray. To answer this question, one has to consider literature in its bibliographical sense. The bibliometric analysis of thermal spray is supposed to delineate the related map and territory, to quote a literary reference. The most recent analysis, which was presented by K.A. Khor (NTU/Singapore) at the March 2015 Cold spray Club meeting, relates to cold spray. This original approach to the process, based on the assessment of the number of publications per sub-domain (Fig. 16), ascertains that cold spray can be considered as a cold revolution (i.e. “Der koude revolutie” to stay in Houellebecquian references which are numerous in thermal spray (“The Elementary particles”, “Platform”, …)) in the thermal spray world. This has resulted in a real industrial craze which has not yet died down. The significant increase of the number of publications on cold spray till a peak in 2003, corresponds to the development of the cold spray technology. In addition, the continuous growth in the number of citations until stabilization in 2010, concurrently with a decrease of the number of publications, does exhibit the process expansion, including in industry (Fig.16).

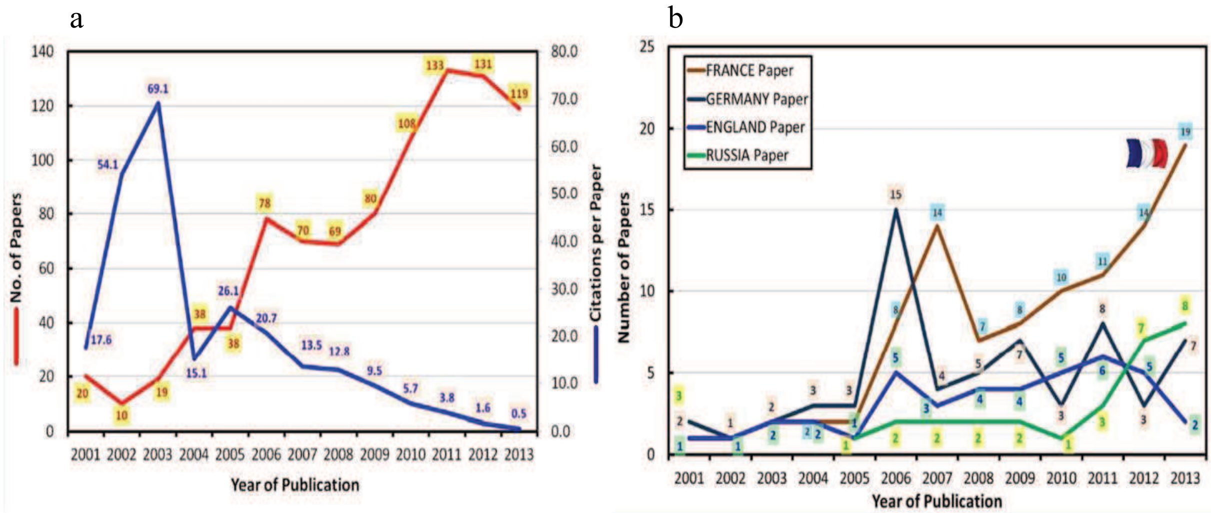

Fig.16: Bibliometric analysis of cold spray, showing the yearly evolution of the, a) Total number of publications and citations, b) Number of publications per country, after K.A. Khor, 2015, [23].

The subject matters in the articles show the same evolution. These are very diversified, i.e. from fluid mechanics to materials properties through technology, when considering the whole evolution from the very beginning of cold spray (Fig. 17a). In contrast, these have focused on some specific issues in the past few years (Fig. 17b), primarily materials and related properties. The powder issue is most prominent as one of the central volcanoes in the topic island in Fig. 17b.

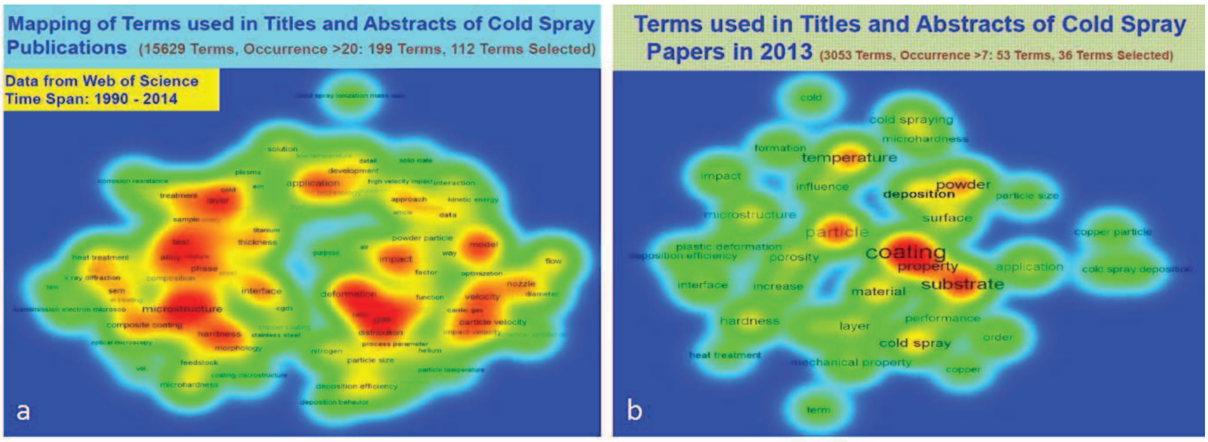

Fig.17: Topic maps of articles in the cold spray area, a) Over the 1990-2014 period, b) In 2013. The colors are all the warmer because the number of publications is high, after K.A. Khor, 2015, [23].

Conclusion

Thermal spray resonates with all arts, as attempted to be shown by this article through examples. This universality, which is prime characteristic of art, underlines, if needed, the multidisciplinary nature of the studies of this process. One would be tempting to say in a rather too easy way that thermal spray is in itself an art, which would be worthy of being the so-called “11th art” in the non-exhaustive list of arts. However, even though thermal spray is not still ready to enter the pantheon of arts, maybe one day thermal spray will be termed as “therm-art spray”.

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