BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI

Volumul 65 (69)
Numărul 1-4

Secţia
ŞTIINŢA ŞI INGINERIA MATERIALELOR

2019 **Editura POLITEHNIUM**

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
PUBLISHED BY
“GHEORGHE ASACHI” TECHNICAL UNIVERSITY OF IAŞI
Editorial Office: Bd. D. Mangeron 63, 700050, Iaşi, ROMANIA
Tel. 40-232-278683; Fax: 40-232-211667; e-mail: buletin-ipi@tuiasi.ro

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S U M A R

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
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Volume 65 (69), Number 1-4 2019

Section

MATERIALS SCIENCE AND ENGINEERING

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BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 65 (69), Numărul 1-4, 2019
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SEVERE PLASTIC DEFORMATION PROCEDURES - REVIEW

BY

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Received: November 1, 2019
Accepted for publication: December 19, 2019

Abstract. The technological progress involves more and more new materials having special properties given by special structures obtained by the applying of various technologies. The severe plastic deformation of metallic materials can produce advanced materials with special properties given by the very well control of the grain size, in the range of 150 nanometers or less. The method of severe plastic deformation is materialised by a series of procedures and techniques. In this paper will be presented the following procedures: equal channel angular pressing – ECAP; high pressure torsion – HPT; accumulative roll bonding – ARB; cyclic extrusion compression – CEC; cyclic closed die forging – CCDF; repetitive corrugation and straightening – RCS; severe torsion straining – STS. From this set of procedures the most used are ECAP, HPT, ARB and CCDF.

Keywords: equal channel angular pressing; high pressure torsion; accumulative roll bonding; cyclic extrusion compression; cyclic closed die forging; repetitive corrugating and straightening; severe torsion straining.

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1. Introduction

The rapid industrial development at the planetary level as well at the national level requires a growth of the weight of products with a higher degree of processing of materials that involve a big quantity of work, technical intelligence and implicitly a minimum consumption of raw materials.

In this respect, as the industrial evolution indicates, for the recent past years the technique of metallic materials processing by severe plastic deformation shows a more and more interest.

2. Severe Plastic Deformation Procedures

The main severe plastic deformation procedures remain also today the most used and in equal measure the most divers as technological schemes and variants.

2.1. The Equal Channel Angular Pressing (ECAP)

The ECAP procedure can be defined a the plastic deformation done by the extrusion of the semi product in angular channels of constant section. The cross section of the semi product remains constant and the degree of deformation imposed can be obtained by achieving a calculated number of extrusions operations.

Fig. 1*a,b,c* shows by the means of schemes the lateral extrusion processes that represent, in fact, a double axial extrusion of the semi product (Kudo, 1974; Hazra, 2011). Fig. 1*d* and *e* indicate the extrusion process in which by pure shear can have a repeated character so the plastic deformation is produced without making modifications on the transversal dimensions of the processed part. These processes are known by the name of ECAE (Equal Channel Angular Extrusion) or ECAP.

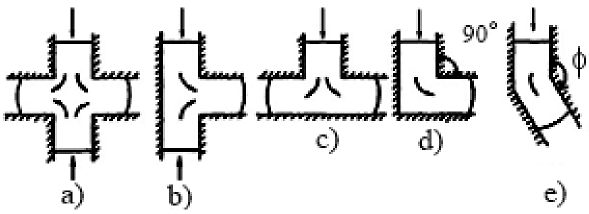

Fig. 1 – Schematic representation of lateral extrusion processes (Kudo, 1974).

Segal (Segal, 1995; 2002), proposed this technique for obtaining a material having a structure characterized by ultra fine grains. Although the ECAP procedure is applied generally to solid materials it can be used also for consolidating metallic powders. Kudo and the collaborators (Matsumoto *et al*., 1998; Nemoto *et al*., 1998), have performed lateral repeated extrusions with counter pressure for consolidating a pure aluminum powder (Hea *et al*., 2010). In the years 1990 the development of materials with ultra fine grains was made by the same method by Valiev *et al*., (Valiev *et al*., 2006), Horita *et al*., (Furukawa *et al*., 2001; Kamachi *et al*., 2003), Azushima and the collaborators and others, (Huang *et al*., 2001; Prangnell *et al*., 1997; Furuno *et al*., 2004; Zhang *et al*., 2009).

The schematic representation of the ECAP technique is given in Fig. 2. The sample is laterally extruded and deformed by shearing with the dead zone in the outside corner of the channel. At the processing by lateral extrusion, the deformation is being produced from the ϕ angle zone at the angle subscribed by the arc ψ.

For ϕ = 90° and ψ = 0°, the total deformation corresponding for a passing is:

$$\varepsilon_1 = \frac{2}{\sqrt{3}} cot \frac{\varphi}{2} \quad (1)$$

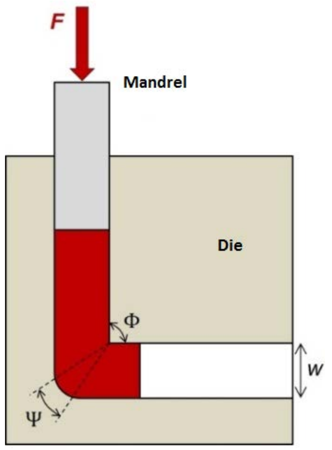

Fig. 2 – Schematic representation of the ECAP procedure (Comăneci, 2015).

After *n* passings the deformation becomes: ε_t

$$\varepsilon_t = \varepsilon_1 + \varepsilon_2 + ... + \varepsilon_n \quad (2)$$

or:

$$\varepsilon_t = n \cdot \frac{2}{\sqrt{3}} cot \frac{\varphi}{2} \quad (3)$$

In Fig. 3 it is shown the plastic deformation of a cubic element passing through the ECAP technique (Azushima *et al*., 2008). The channel is executed at an angle of 90°, the sample is introduced into the channel and can be pressed through the die using a mandrel.

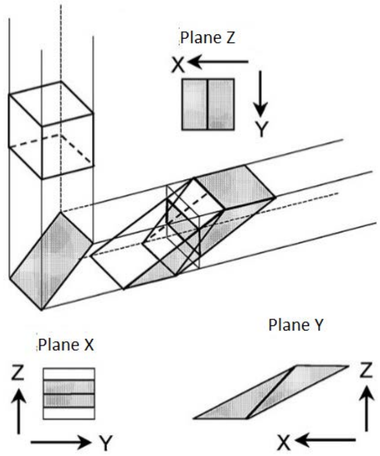

Fig. 3 – Plastic deformation of a cubic element by the ECAP procedure at a single passing (Azushima *et al*., 2008).

There are four basic routes specific for the fundamental process of flowing in the ECAP procedure, Fig. 4:

– on the route A, the sample is being pressed without rotation;

– on the route B_A, the sample is rotated with 90°, in alternating senses between passings;

– on the route B_C, the sample is rotated between passings, with 90° in ant trigonometric sense after each passing;

– on the route C the sample is rotated with 180° between passings in a trigonometric sense.

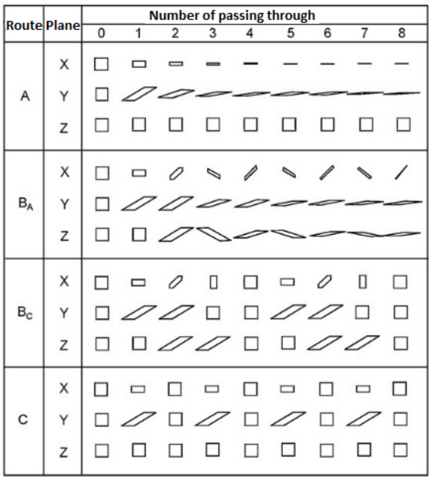

Fig. 4 – Basic routes for deformation by shearing specific for ECAP procedure (Furukawa *et al*., 2001).

The macroscopic deformations shown in Fig. 4 demonstrate the fact that the influence of the processing route must be taken into consideration for developing a ultra fine grain microstructure (Furukawa *et al*., 2001). Horita *et al*. have shown that an ultra fine grain microstructure in pure aluminum after 10 passings through the technological route A was the same with the one obtained after 4 passings through the technological route B_C.

The researches done by various authors lead to the development of a variety of technological techniques for the ECAP procedure.

Azushima and the collaborators, (Azushima and Aoki, 2002; Kim *et al*., 2003; Ma *et al*., 2005a; Ma *et al*., 2005b), have proposed the repetitive lateral extrusion with counter pressure. This is a process in which a high counter pressure is being applied, as shown in Fig. 5, pressure necessary to produce an uniform deformation by shearing and for preventing the defects inside the processed part. The sample is extruded laterally between the mandrels A and B and at the same time the mandrels C and D are fixed. In this process, the total deformation become $\varepsilon = 1.15$ after a passing.

The mandrel A controlled by the function generator travels with a constant speed and the mandrel B generates a constant counter pressure (Miyahara *et al*., 2006; Mathisa *et al*., 2011). Recently, there have been developed sets of ECAP dies that achieve the counter pressure ECAP procedure in a computer assisted manner in what concern the counter pressure control.

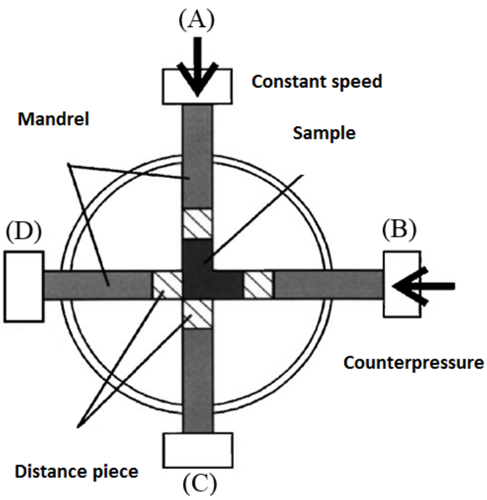

Fig. 5 – Schematic representation of the ECAP procedure with counter pressure (Kim *et al*., 2003).

Nisida and the collaborators, (Nishida *et al*., 2001; Ma *et al*., 2005b), have developed a rotative ECAP die, shown in Fig. 6 that contains two channels with the same cross sections that intersect in the middle under a straight angle, aiming to eliminate the conventional limitation when the sample had to be drown out from the die and then reinserted after each passing through.

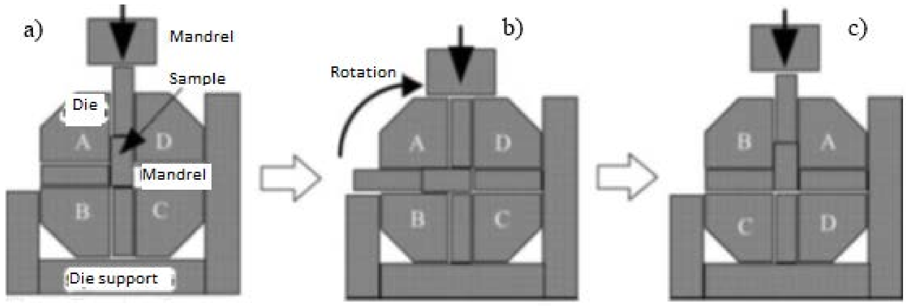

Fig. 6 – The ECAP method using a rotative die (Nishida *et al*., 2001): *a*) initial state; *b*) after a passing; *c*) after 90° rotation of the die.

First, the sample is being introduced into the die with the mandrel positioned as shown in Fig. 6*a*. After the pressing of the sample, shown in Fig. 6*b*, the die is being rotated with 90° and such the sample is ready to be pressed again, as shown in Fig. 6*c*. By using this device a sample can be pressed with the mandrel A using counter pressure from the mandrel B, in a similar way as the one shown in Fig. 5. With the help of the rotative variant of the ECAP procedure one can apply also repetitive pressure (Nhisida *et al*., 2001; Ma *et al*., 2015a). This process is being equivalent with the technological route A shown in Fig. 4.

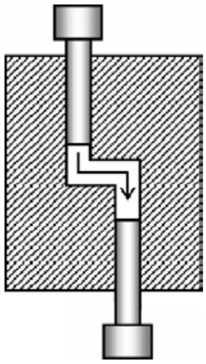

Fig. 7 – Schematic representation of the ECAP procedure with channel in two corners (Ma *et al*., 2005a; Ma *et al*., 2005b).

In the same way as in the repetitive ECAP procedure it was developed a variant destined for the reduction of the repetition numbers by growing the number of corners of the channel inside the die.

Using channels with two corners, the force after a passing through doubles and the productivity of the ECAP procedure enhances. A counter mandrel that produces a supplementary pressure, Fig. 7 can be a possible solution to be used on hydraulic ordinary presses.

Presses with two opposite rams and having the same power can be used for a cyclic process. Is such a process the total deformation becomes e = 2.3 after one passing.

2.2. The Procedure „ High Pressure Torsion” – HPT

The procedure HPT (high pressure torsion) was investigated for the first time by Valiev (1997a; 1997b). The HPT process is a continuous process for severe plastic deformation that consists in shearing by torsion of the material between two anvils, a fixed one and a rotating one (Gurău *et al.*, 2015a). The torsion momentum necessary is determined by the friction forces on the contact areas between the semi product and the anvil.

The HPT procedure produces a more efficient finishing of the structure by comparing with the ECAP technique. However the application of the HPT were restricted to achieving some disks (the so called HPT disk), Fig. 8.

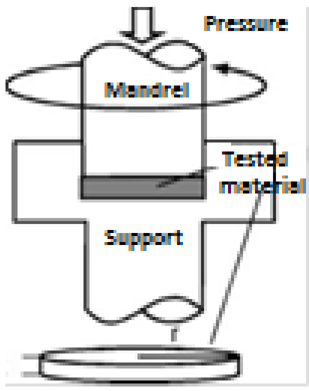

Fig. 8 – The principle scheme of the high pressure torsion procedure - HPT (Sakai *et al.*, 2005).

This procedure has the disadvantage that it uses samples in a disk shape, relatively small sizes and it is not usable for producing big semi products (Wei *et al.*, 2006; An *et al.*, 2012; Gurău *et al.*, 2015b). Another disadvantage is given by the fact that the microstructures produced are dependent on the applied pressure and of the precise position inside the disk.

For solving the problem, Horita and collaborators have developed a HPT procedure that uses a global sample, Fig. 9 (Sakai *et al.*, 2005; Saad *et al.*, 2016).

This variant of the process is designated as Bulk – HPT for being able to compare with that called Disk – HPT.

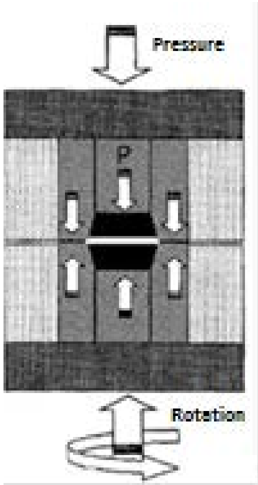

Fig. 9 – The principle scheme of the Bulk - HPT procedure (Azushima and Aoki, 2008).

The torsion angle is given by the relation:

$$\gamma(r) = \frac{2\pi n r}{l} \quad (4)$$

where: r is the distance between the disk axes; n – number of rotations; l – thickness of the sample.

According to the plasticity criterion of von Mises', the equivalent plastic deformation is given by the relation:

$$\varepsilon(r) = \frac{\gamma(r)}{\sqrt{3}} \quad (5)$$

2.3. The Accumulative Roll Bonding Procedure – ARB

The accumulative roll bonding (ARB) has been developed for the first time by Saito an collaborators (Saito *et al.*, 1998; Lee *et al.*, 2002a; Saito *et al.*, 1999). The principle of the ARB technique is shown in Fig. 10.

The accumulative roll bonding is a severe plastic deformation technique that consists in successive rolling of a product obtained by transversal cutting of the same material after a previous rolling and the superposing of the parts followed by a new rolling with big deformation degrees, more than ≥ 50%, and without changing the distance between the rolling cylinders.

Applying such a deformation produces the bonding of the material and the refinement of its microstructure.

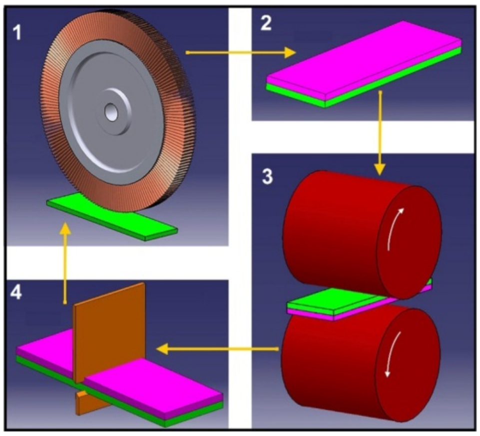

Fig. 10 – Principle scheme of the ARB procedure (Zabihi *et al*., 2016).

The resulted deformation after n completed cycles, in the ARB technique can be determined using the relation:

$$\varepsilon = \frac{\sqrt{3}}{2} ln(r), r = 1 - \frac{t}{t_0} = 1 - \frac{1}{2^n} \quad (6)$$

where: t_0 is the initial thickness of the semi product (strip); t – actual thickness after rolling; n – number of rolling cycles performed.

Applying this method on sheets or strips, having in mind the finishing of grain size down to nanometric dimensions shows the advantage of a continuous deformation of some products in an industrial volume (Lee *et al*., 2003; Schmidt *et al*., 2011; Reihanian *et al*., 2014).

Successfully obtaining of a laminated product, nanostructured by ARB, is conditioned by the adhesion (cohesion) between layers (Heason and Prangnell, 2002; Cao *et al*., 2002; Alizadeh *et al*., 2011). If the adhesion between layers does not take place the severe plastic deformation procedure can not continue and the final purpose, of obtaining nanostructured rolled products can no longer be achieved (Yazdani and Salahinejad, 2001; Das *et al*., 2006; Azada and Borhani, 2016).

The ARB is represented by a set of conventional rolling applied on sheets or strips initially superposed (Lee *et al*., 1999). Before rolling, the two contact surfaces must be prepared (cleaning: oxides removing, degreasing etc.) for achieving a resistant adhesion and then they are being put one over another and are laminated together, with a degree of reduction of 50%.

After using the ARB method for severe deforming it was found that the microstructure obtained has a lamellar shape, the grain boundaries decrease and the orientation of grains grows with the deformation degree. Studies have shown the existence of appreciable difference in the evolution of microstructural parameters obtained by conventional rolling by comparing with those obtained by accumulative roll bonding (Park *et al*., 2001; Xing *et al*., 2001; Lee *et al*., 2002b; Hsieh *et al*., 2003).

2.4. The Cyclic Closed Die Forging Procedure - CCDF

The principle of the cyclic closed die forging procedure (CCDF) has been developed by Amit K. Ghosh and collaborators (Ghosh, 1988). He patented a procedure (patent US4721537) that supposes the obtaining fine grains at some aluminum alloys using deformation after three axes, Fig.11*a*.

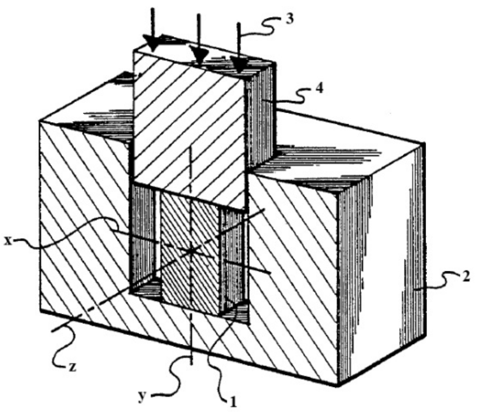

Fig. 11*a* – Scheme of the procedure patented by Amit K. Ghosh in 1988 (US4721537): 1 - semiproduct; 2 - die; 3 - deformation force; 4 - mandrel; x, y, z – main coordinate axes.

The semi product is first heat treated, left for a while to precipitate and than hot deformed along those three main axes (x, y, z) until achieving a cumulated degree of deformation 8.0. This deformation on three axes is being achieved by pressing the semi product along the y axe, the displacement on z being restricted, forcing it to deform on the x axe direction. After deforming the semi product 100%, it is rotated and pressed along the x axis. The semi product is rotated again and pressed along the z axis. These three operation complete a first cycle of deformation and after them it result a semi product deformed along three axes, but having the same sizes as the initial semi product (Ghosh, 1988).

Amit K. Gosh used for exemplification the aluminum alloy Al7075 having initially a grain size of about 100 µm, the sizes of the semi product being 38x19x19 mm. The sample was first treated at 482°C, left for precipitation for 24 h at a temperature of 121°C.

The semi product was then deformed after the three axes as previously described in 15 stages (5 complete cycles), reducing its height from 39 mm to

19 mm in each stage, the deformation temperature being 300°C. After the last deformation cycle the semi product was again treated at 482°C for 30 min for completing the crystallization process and dissolving the precipitates.

The size of the grains obtained after 5 cycles of deformation was 4-5 µm, obtaining a significant finishing of the granulation.

On this bases it was developed the cyclic closed die forging procedure.

(Zherebtsov *et al*., 2009; Padap *et al*., 2010; Miura *et al*., 2013; Tang *et al*., 2013; Wei *et al*., 2013; Rao *et al*., 2014), procedure shown schematically in Fig. 11*b*.

The semi product is firs compressed in the vertical position and then in a horizontal direction (Zherebtsov *et al*., 2004; Kuziak *et al*., 2005, Ghosh *et al*., 2000, Cherukuri and Srinivasan, 2006; Han, 2010; Cazac, 2013a, 2013b; Cazac, 2014a, 2014b,2014c; Cazac, 2015; Cazac, 2017; Cazac, 2018a, 2018b).

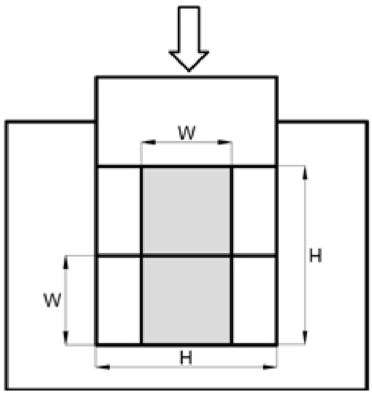

Fig. 11*b* – The principle scheme of the procedure CCDF (Ghosh *et al*., 2000).

The equivalent degree of deformation for each stage of the operation is given by the relation:

$$\varepsilon = \frac{2}{\sqrt{3}} \cdot ln\left(\frac{H}{W}\right) \quad (7)$$

where: *H* is the height of the sample; *W* – width of the sample.

2.5. Other Procedures

During time there have been developed more severe plastic deformation procedures. As we have presented previously the procedures ECAP, HPT and ARB are the procedures most referenced in the literature. The CCDF procedure has relative few references. In the following pages we shall present other severe plastic deformation techniques, but less used, known as: CEC, RCS, STS, REU, RE.

2.5.1. The Cyclic Extrusion Compression Procedure, CEC

The CEC procedure was developed by Korbel and collaborators (Korbel *et al*., 1981), being represented schematically in Fig. 12. In the case of CEC, a sample is being introduced into a die and then extruded repeatedly, beck and forth. This process was invented for enabling the arbitrary deformation of a sample maintaining the original shape even after n passings (Korbel *et al*., 1981; Rosochowski *et al*., 2000).

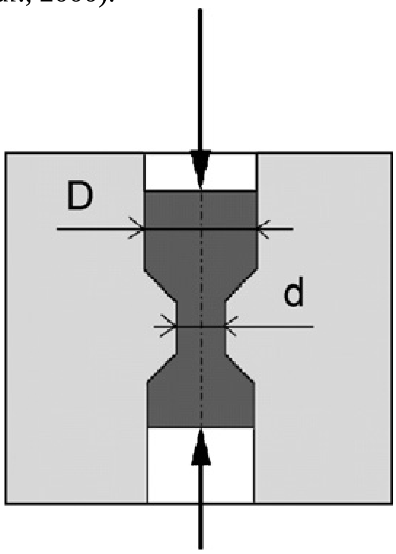

Fig. 12 – The principle scheme of the cyclic extrusion compression procedure - CEC (Rosochowski *et al*., 2000).

The equivalent cumulated deformation can be expressed by the relation determined experimentally:

$$\varepsilon = n \cdot 4ln\left(\frac{D}{d}\right) \tag{8}$$

where: *D* is the diameter of the die container; *d* – the diameter of the profiled port of the die; *n* – number of deformation cycles.

2.5.2. The Repetitive Corrugation and Straightening Procedure, RCS

The principle of the repetitive corrugation and straightening procedure (RCS) developed by Huang and collaborators in 2001 is represented schematically in Fig. 13 (Huang *et al*., 2001). The procedure consists in the bending of a straight bar with tools for a corugate shape and then the restauration of the shape of the bar using flat tools for deforming.

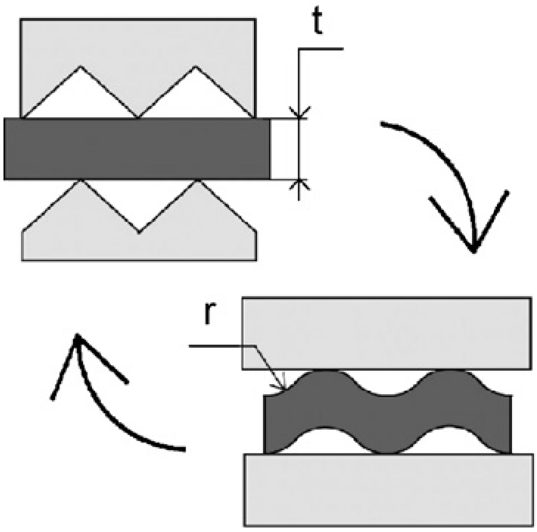

Fig. 13 – The principle scheme of the repetitive corrugation and straightening procedure RCS (Huang *et al*., 2001).

The equivalent deformation for a single passing is given by the relation:

$$\varepsilon = 4ln\frac{[(r+t)/(r+0{,}5t)]}{\sqrt{3}} \tag{9}$$

where: t is thickness of the sample; r – the curve on the corrugated zone.

By repeating cyclically this procedure significantly big mechanical stress can be induced in the processed part.

2.5.3. The Severe Torsion Straining Procedure – STS

The principle of the severe torsion straining procedure – STS was developed by Nakamura and collaborators and is schematically shown in Fig. 14 (Nakamura *et al*., 2004). The process consists in the achieving of a heated zone and the creation of a torsion force in zone by the rotation of one end of the rod. During this time the rod is displaced along the longitudinal axis and locally a strain is created. In this way a continuous severe plastic deformation is achieved all along the rod.

For efficiently create a torsion force the heated zone must be narrow and the rotation speed of the rod must be big by comparing with the displacement speed of the rod. More over, adding a modification in the cooling system enable the better localization of the heated zone and such an enhancement of the torsion force.

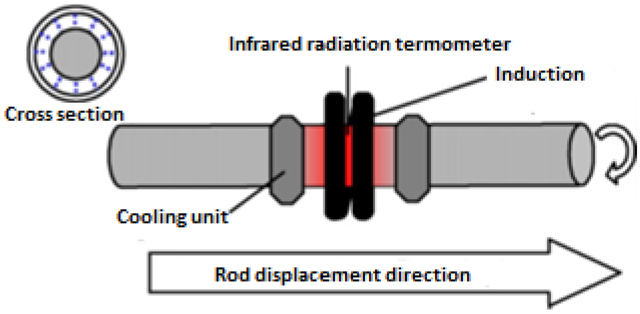

Fig. 14 – The principle scheme of the severe torsion straining procedure - STS (Nakamura *et al*., 2004).

2.5.4. The Repetitive Extrusion and Upsetting Procedure - REU

The principle of the repetitive extrusion and upsetting procedure (REU) was developed and patented by L. Zaharia in 2008 (Zaharia *et al*., 2014). The process begins by the extrusion of a semi product to lengthen the grains. Because in the deformation zone it remains a not deformed end a new semi product is being inserted for completing the deformation of the first semi product.

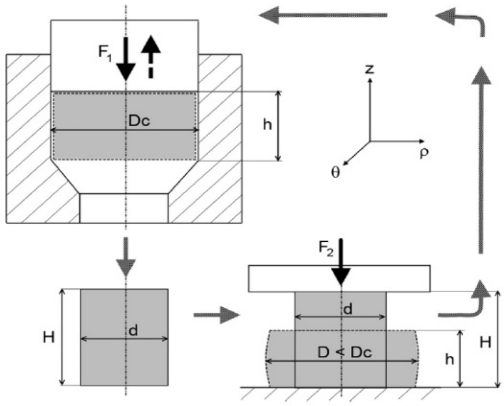

Fig. 15 – The principle scheme of the repetitive extrusion and upsetting procedure - REU (Zaharia *et al*., 2014).

After the complete extrusion, the first semi product is being upset until the initial diameter is reached and the extrusion procedure can be repeated Fig. 15.

The sizes of the extruded rod must fulfill the condition $H/d \leq \Psi_a$ where $\Psi_a \leq 2.3$ (Lange, 1985) to prevent buckling during upsetting.

The REU procedure consists in the combining of two well known conventional plastic deformation procedures, without using instruments and/or supplementary devices.

2.5.5. The Repetitive Extrusion Procedure - RE

The repetitive extrusion procedure (RE) was patented by L. Zaharia in 2008, Fig. 16.

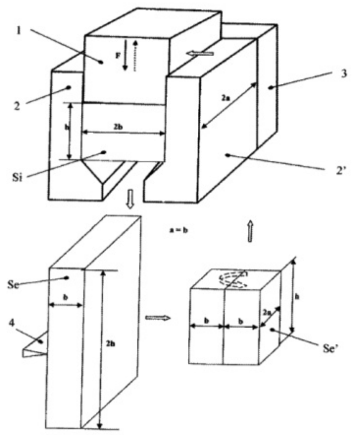

Fig. 16 – The principle scheme of the repetitive extrusion procedure - RE (Zaharia, 2008).

This procedure uses an extrusion die having the container of square cross section shape, in which the initial semi product S_i is being introduced. This one is being pushed by the mandrel 1 towards the calibration zone of rectangular cross section shape resulting the extruded semi product S_e. This semi product is cut in two equal parts with the knife 4, the parts being assembled so a perfect square section of a new semi product is being produced. This assembly is reintroduced in the die container and the process is then repeated until the achieving a ultrafine granulation (Zaharia, 2008).

3. Conclusions

In the microstructural era (1930-1990) the main procedures for severe plastic deformation were outlined: equal channel angular pressing – ECAP; high pressure torsion – HPT; accumulative roll bonding – ARB; cyclic closed die forging – CCDF. After this, by perfecting these procedures it had been possible to obtain nanostructured semi products with special mechanical and physical properties, entering in this way in the new, nanostructural era.

Notable in the field of severe plastic deformation is the contribution of the Romanian school and especially of Iasi by patenting by professor L. Zaharia in the period 2008-2013 of two severe plastic deformation namely: the repetitive extrusion and upsetting – REU and the repetitive extrusion - RE. Equally remarkable, in the field of severe plastic deformation, are the works of professor R.I. Comăneci, works published in prestigious magazines and publishing houses.

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PROCEDEE DE DEFORMARE PLASTICĂ SEVERĂ - REVIEW

(Rezumat)

Metoda deformării plastice severe este materializată printr-o serie de procedee. În cadrul acestei lucrări vor fi prezentate următoarele procedee: presarea în canale unghiulare egale (equal chanel angular pressing - ECAP); torsiunea sub presiune ridicată (high pressure torsion - HPT); laminarea adezivă cumulativă (accumulative roll bonding - ARB); extrudare prin compresie ciclică (cyclic extrusion compresion - CEC); forjare ciclică în matriţă închisă (ciclic closed die forging - CCDF); ondulare şi îndreptare repetitivă (repetitiv corrugated and straightening - RCS); tensionarea prin torsiune severă (severe torsion straining - STS). Dintre acestea cele mai utilizate sunt procedeele ECAP, HPT, ARB şi CCDF.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 65 (69), Numărul 1-4, 2019
Secţia
ŞTIINŢA ŞI INGINERIA MATERIALELOR

A REVIEW OF REALIZATION OF INTEGRATED CIRCUITS BY LCVD TECHNIQUE

BY

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Received: November 1, 2019
Accepted for publication: December 19, 2019

Abstract. The paper presents a synthesis of the Laser-induced Chemical Vapour Deposition (LCVD) method used to obtain a complete integrated circuit by the deposition of chemically vapour thin films, CVD (Chemical Vapour Deposition). The paper analyses the pyrolytic mechanism of the methods and the deposition of Ni and Cu using precursors such as $Ni(CO)_4$ and Cu(hfac)tmvs (copper hexafluoroacetylacetonate trimethylvinylsilane). The deposition methods were theoretically analysed by studying the dynamics of the precursor gas reaction on the surface, the interface phenomena, the mechanism of multicomponent deposition and the role of various parametric lasers in increasing the deposited film and in terms of practical use and toxicity of substances. used in the submission process.

Keywords: LCVD technique; precursor gas; pyrolysis; laser beam; integrated circuit.

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1. Introduction

Given the multitude of elements that need to be implemented and the extreme miniaturization that has been achieved, the design of integrated circuits used in the modern electronics industry is particularly complex. Achieving them through classical methods would require long periods of time, which can be on the order of years, which is a serious shortcoming in the competitive struggle between the various companies producing computers, cell phones and televisions. In this context, any method that can reduce the design and realization time of circuits is of great interest. As the realization of integrated circuits precedes the introduction in series production, their performance must be verified by producing and testing several prototypes. If the measurements deviate or find defects from the proposed purpose, the design-realization-prototype-verification cycle must be resumed. These cycles can last from a few weeks to a few months, to which are added the costs of small series production.

Because an integrated circuit contains tens and hundreds of thousands of components (resistors, capacitors, transistor diodes and the corresponding connections between them) very complex computer software is used to achieve its design. The first step in the manufacturing process includes making the circuit elements and interconnecting them according to the adopted scheme. The substrate on which the circuit is transferred can be a thin silicon plate or a single semiconductor crystal. The circuit is then created by successively depositing thin layers of metals, insulators and sometimes other semiconductor materials (containing *n* or *p* type impurities), etching portions of the layer and doping with su ions with chemicals (Fonstad, 1994). In order to realize the complexity of the design and realization processes, in Fig. 1 shows schematically the process of making MOSFET transistor with *n* channel (https://www .allaboutcircuits.com). The objective of this first phase is to add *p*-type impurities on some areas on the chip surface.

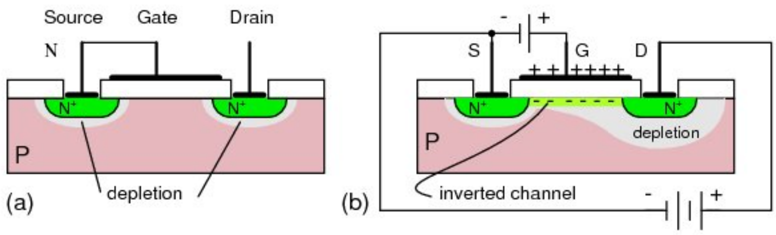

Fig. 1 – An example of a n-channel MOSFET transistor, (*a*) for a 0V gate bias and (*b*) positive gate bias (https://www.allaboutcircuits.com).

The complete manufacture of an integrated circuit is significantly more complicated as many more complex templates (masks) are needed. Extremely sophisticated techniques for the selective engraving of materials, light exposure of photosensitive material and other processes are also required.

In order to edit and create a circuit, as well as to analyze its efficiency, various techniques have been developed. In the early 1990s, when the size of linear conductors was still on the order of microns, the laser cutting technique was used (Nd:YAG laser pulse) (Soden and Anderson, 1995).

The problem of editing integrated circuits has become much more difficult with the advent of new miniaturized integrated circuits. Miniaturization was performed with ion-focused beam technology – the original method for multilateral modification of integrated circuits and analysis of their defects. The same focused ion flux-based method has proven to be very useful and general for both etching and thin-film deposition. However, the method has serious shortcomings for circuit editing, especially in the case of depositing longer distance connections with an acceptable resistance (as low as possible), a process that requires too much time (Doorselaer *et al*., 1993; Silverman, 1996).

The development of modern microelectronics required the continuous improvement of manufacturing technology and materials science, such as: the replacement of aluminum conductors with copper - this improving electrical conductivity and resistance to electromigration (Edelstein *et al*., 1997; Andricacos *et al*., 1998). Another example is the introduction of low-passivity dielectric materials for passivation and circuit isolation and high-passivity dielectrics for MOS transistors (Kingon *et al*., 2000). One of the most used techniques for the production of thin films (functional or protective) is the chemical deposition of metals in the vapor phase, CVD (Chemical Vapor Deposition) (Creighton and Ho, 2001). In the thermally activated CVD method, the solid film is formed by a chemical reaction of the gaseous precursor on the heated surface of the support. Selective deposition on certain parts of the surface is usually done by stenciling or lithographic methods. This adds additional steps, which can be difficult or even impossible to apply on curved (non-plane) substrates.

The thermal sensitivity of some substrates limits the use of CVD in case of chemical reactions that would be of interest but which require too high reaction temperatures. The initiation of the CVD reaction by the local heating effect or by a laser beam can compensate for these deficiencies.

Laser-assisted Chemical Vapor Deposition (LCVD) is a method that allows the deposition of semiconductors, metals and dielectrics on various materials used as a substrate (Roy, 1988).

Compared to the classical CVD method, LCVD is a selective deposition method with spatial resolution within a few micrometers, relatively low deposition temperature on the substrate and does not require fabrication templates or subsequent lithography stages. Moreover, the power of the laser beam that induces the temperature in the substrate can be varied in fractions of a second, thus ensuring a quick control of the morphology of the deposited layer.

2. The Principle of the LCVD Method

Laser-induced Chemical Vapor Deposition (LCVD) has been studied and applied in deposition technology, microelectronics or optics for the last 20-25 years (Duty *et al*., 2001; Remes, 2006; Alemohammad and Toyserkani, 2010; Mahamood and Akinlabi, 2018). The principle of the LCVD method is shown schematically in Fig. 2 (Van de Burgt, 2014). A focused laser beam is scanned and positioned by a process computer, which controls movement.

Deposition takes place by chemical reactions of pyrolysis, photolysis or both. These reactions take place in the boundering of the laser beam (Ehrich and Tsao, 1989; Ehrich and Tsao, 1983). The reaction zone, delimited locally, makes it possible to deposit the conductive lines with a resolution of a few micrometers by scanning the laser flux focused on the surface of the substrate. In this way it is possible to submit new electrical connections to an already processed integrated circuit, connections that would be necessary for the analysis of the prototype operation test.

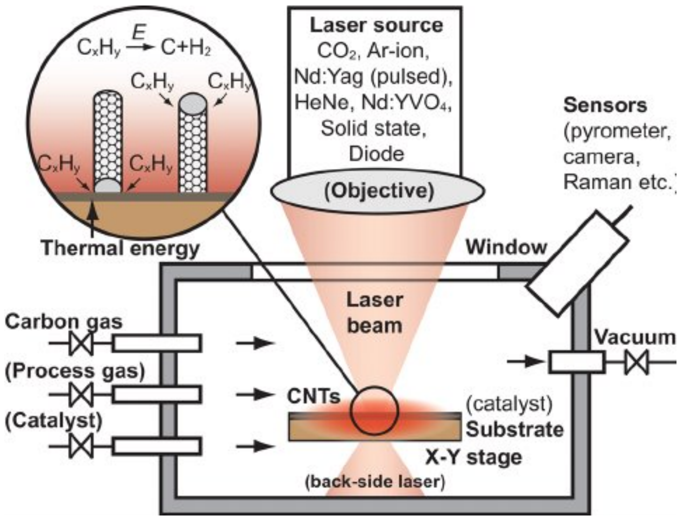

Fig. 2 – General schematic for a laser-assisted chemical vapor deposition setup including the laser source, gas input, substrate and catalyst, stage, and sensors (Van de Burgt, 2014).

The LCVD method is a combination of chemical methods, laser techniques and optical methods, which are conveniently combined to make reproducible processing results possible. Acceptable deposition parameters are easy to find when the deposition is made on a homogeneous substrate such as a silicon chip. The problem becomes much more interesting when it is necessary to deposit connections of constant thickness and width and with certain electrical properties on integrated circuits that present a corrugated or rough surface relief and with various materials. This is the case of re-editing a circuit with a new submission (Kanaujia *et al*., 2017). The resolution and quality of the deposition is mainly determined by the temperature distribution on the substrate surface, which in fact depends on the size of the localized laser flux, the conductivity and the adsorption coefficient of the material from which the substrate is formed. LCVD allows the manufacture of planar and non-planar structures that are difficult or even impossible to achieve by conventional processing methods. A good example of the versatility of LCVD is the manufacture of three-dimensional microbools, which was presented by Westberg *et al*. (1993). Subsequent applications of LCVD in microelectronics consist of gold deposits in the case of multi-chip modules (MCM), repair of line defects (Wassick and Economikos, 1995) and deposition of gold nodules on flip-chip circuits (Metzger and Reichl, 1997).

The deposition mechanism by the LCVD method is much more complicated than the conventional one, made by the CVD method, this due to the micrometric dimensions of the reaction area (of the order of 5 μm) and the very complex dependence of the chemical reaction temperature temperature induced by the focused laser flux (Mazumder and Kar, 1995). Laser-assisted vapor deposition can take place through two essential mechanisms: pyrolytic deposition and photolytic deposition, which are related to how the chemical reaction is initiated and conducted by the laser beam.

In the ***photolytic LCVD method***, the photons of the laser flux are absorbed directly by the gas molecules, some chemical bonds are broken and the chemical reaction is initiated. Photolysis takes place either by the absorption of a single photon or by the participation of several photons, depending on the precursor used and the energy of the photon (Alm, 2007). However, there are many systems in which the mechanism involves both pyrolytic and photolytic variants, simultaneously contributing to the reaction, although only one is dominant in the deposition process.

The first works on photolithic LCVD deposition referred to gold deposition in the process of editing an integrated circuit prototype (Shaver *et al*., 1987), but the extremely low resistivity obtained (250 μΩ·cm) was unacceptable. Moreover, the photolithic deposition of metals by the LCVD method often induces an inclusion in the deposited film of a large amount of carbon or reaction by-products of an organic nature, the deposited film having unsatisfactory electrical and mechanical properties. In many cases the photolytic deposition of the metal requires high energy photons, which makes the complexity of the system and the costs high. Deposits by the photolithically initiated LCVD method are more convenient for lithographic projection on large surfaces (flat pattern), when the substrate is thermally sensitive.

3. The Pyrolytic Mechanism of the LCVD Method

In the pyrolytic LCVD method, the molecules in the precursor vapors do not absorb laser photons but the local heating of the substrate by the focused laser spot initiates the thermal thermal reaction (Koutlas and Vlachos, 2003).

The first works in the field, those of Auvert (1993) on the use of the LCVD method by the pyrolytic variant when depositing tungsten from tungsten fluoride (WF_6), showed that the process is not usable on a silicon or SiO_2 support (due to the formation of hydrochloric acid - HF), silicon being the basic material for the realization of integrated circuits. For many other systems, the pyrolytically controlled LCVD method has proven to be much better and safer. Given the shortcomings of the photolytic variant, the pyrolytically controlled LCVD method deposits proved to be more suitable for editing integrated circuits. For this reason, only this method and some of its applications will be presented in this paper. The pyrolytic process resembles the usual CVD process, except that the support on which the deposition is made is heated only locally, where the deposition is made, the necessary energy being provided by the laser beam, while in CVD the substrate is heated entirely. In principle, it is possible for the same material to be deposited in both CVD and LCVD (Dobrzański *et al*., 2014).

The essential difference between LCVD and CVD is that in CVD the precursor gas flow is one-dimensional, while in LCVD the precursor gas flow is three-dimensional and has a hemispherical shape in the reaction zone. The precursor molecules decompose due to the collision with the hot surface of the support excited by the laser beam (Nassar and Dai, 2003).

Because the spot size of the focused laser beam is only a few microns the area of the substrate on which the beam does not fall is not affected; the substrate temperature remains almost unchanged. Both the heating rate and the cooling rate are very high (approx. 1000 K/s), so that the diffusion of the substrate atoms in the deposited film is very low and the film is not contaminated. Moreover, the rapid rise in temperature in a very small hemispherical volume, heated by the laser, can introduce new pathways and chemical reactions between products, which does not happen in CVD. The reaction rate on the support surface is directly proportional to the concentration of gas precursor molecules above the surface and to the diffusion coefficient and inversely proportional to the average free path and the diameter of the heated zone, is the size of the laser spot (Hajduk *et al*., 2009).

Depending on the deposition conditions (total pressure, precursor pressure, laser irradiation and temperature) (Jean *et al*., 2005), the diffusion kinetics (diffusion rate) may be limited either by diffusion (when there are many molecules in the vicinity of the reaction zone and they cannot diffuse quickly enough heated by the surface reaction itself (such as adsorption of reactants and desorption of reaction by-products. Both phenomena affect the rate of global deposition and can lead to possible imperfections of the deposited film, such as the form of volcano.

In order to achieve high deposition velocities, infrared lasers were used because most gaseous precursors do not absorb in the visible range. The essential requirements for successful editing of a circuit are: fast deposition speed, good conductivity and superior spatial resolution. It is also important that the chemical precursor used is compatible with the surface of the integrated circuit substrate, most often silicon, silicon dioxide (SiO_2), silicon oxiazide (Si_2N_2O - silicon oxynitride) or doped phosphosilicate or borosilicate bottles. To exemplify the use of the LCVD method, two significant practical applications will be presented below, used in practice: nickel deposition in $Ni(CO)_4$ by the LCVD method and copper deposition by the LCVD method using an organometallic precursor (Funatsu *et al*., 1996; Brissonneau and Vahlas, 2000).

4. Nickel Deposition in $Ni(CO)_4$ by LCVD Method

Nickel deposition by thermal decomposition of $Ni(CO)_4$ has been reported since the 19th century (Mond - 1892), but the first experiments on Ni deposition by the LCVD method were made by Allen in 1981 (Allen, 1981).

The authors used nickel tetracarbonyl gas ($Ni(CO)_4$) and a CO_2 laser with a wavelength of 10.6 μm as a precursor. Nickel deposition occurs according to the reaction:

$$Ni(CO)_4(g) \rightarrow Ni(s) + 4\ CO(g) \quad (1)$$

The reaction takes place pyrolytically being activated by the high local temperature of the substrate. In this process the limiting parameter for the deposition speed is not the power of the incident laser flux but the reaction kinetics and the properties of the material (Guo *et al*., 2018).

The deposition of linear conductive circuits using $Ni(CO)_4$ as a precursor was the first deposition system used for editing circuits by the LCVD method due to the rather high deposition rate and very good conductivity on various substrates. The investigated parameters were: volumetric growth rate, morphology of the deposited layer and resistivity, depending on the laser power and the partial pressure of the precursor. The principle diagram of the gas circulation installation, used for Ni deposition by the LCVD method, is presented in Fig. 3.

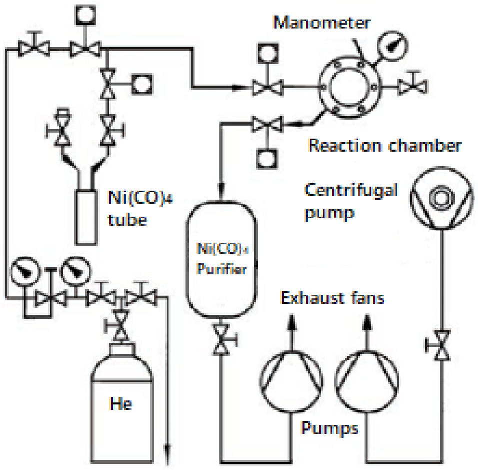

Fig. 3 – Diagram of the gas circulation installation in the Nickel deposition process by the LCVD method (Remes, 2006).

The precursor gas was released into the processing chamber through an electropolyated stainless steel microtubule (nozzle) and a pneumatically operated valve with an electronic monitoring and control system. After completion of the deposition process, the remaining gaseous $Ni(CO)_4$ was neutralized by passing it into a gas sprayer using a centrifugal pump. The nozzle and chamber were purified by washing several times with helium to ensure that the entire amount of $Ni(CO)_4$ was discharged. The chamber pressure was monitored with a Piezovac manometer (Leybold VBacuum - Germany), with an accuracy of 0.1 mbar.

The chemical composition of the deposited nickel (its purity) was characterized by spectrophotometric analysis of a laser ionized microprobe (ND-YAG laser - 266 nm), a method capable of detecting all elements, as well as some molecular compounds, up to a few ppm (parts per million).

The processing system consists of lasers, optical components, gas circulation pipelines and the precursor gas itself. The laser beam can be swept either by acousto-optical deflection or by moving the beam by translating the laser support over the reaction chamber. This arrangement minimizes vibrations, which are undesirable when repairing microcircuits with micrometric resolution.

Another important aspect is the video monitoring of the deposition to ensure the accuracy of the repair and the control of the deposition in real time. In these measurements the precursor gas was diluted with helium to obtain low partial pressures. A series of experiments were also performed using pure, undiluted $Ni(CO)_4$, using gas pressures between 0.2 and 2.2 mbar, laser powers between 50 and 150 mW and a sweeping speed. (scan) of 80 μm/s, kept constant. It has been found that at pressures less than 0.5 mbar the deposition speed is independent of the laser power, while at high pressures the speed increases rapidly with the laser power. The highest growth rate was 4500 $\mu m^3/s$ at a $Ni(CO)_4$ pressure of 2.2 mbar. At precursor pressures above 2.2 mbar and laser powers greater than 150 mW the deposition is uncontrollable, with irregular shapes showing poor adhesion to the passive layer of the substrate.

5. Copper Deposition by LCVD Method Using an Organometallic Precursor

Copper has much better electrical conductivity than nickel (1.7 μWcm, compared to 7.4 μWcm) which is why it was preferentially introduced in semiconductor connection technology. It was necessary to find a gaseous precursor containing copper, which could be easily brought to vapor state and which could be easily reduced to metallic copper. Unlike nickel, copper does not form gaseous carbonyl compounds so that for its introduction into processing.

Chiou *et al*. (1994) and Kim *et al*. (1993) synthesized organic compounds containing cuprous (Cu^+) or cupric (Cu_2^+) ions, which is gaseous at normal temperature: this is copper hexafluoroacetylacetonate trimethylvinylsilane, abbreviated Cu(hfac)tmvs, originally used in CVD deposits.

The copper deposition by the LCVD method was made using laser sources from the visible and ultraviolet domain, through the pyrolytic variant. In the conventional CVD method the deposition of copper from Cu(hfac) tmvs takes place by a disproportionate reaction on the substrate surface, where part of the monovalent copper ions are reduced to metallic copper and another part is oxidized to Cu_2^+ forming Cu(hexafloroacetylacetonate) $Cu(hfac)_2$ and trimethylvinylsilane (tmsv), according to reaction (2):

$$2\ Cu(hfac)(tmvs) \rightarrow Cu^0 + Cu(hfac)_2 + 2\ (tmvs) \quad (2)$$

When copper is deposited by the LCVD method as a carrier gas, hydrogen is used instead of helium, which leads to a doubling of the volumetric growth rate of the deposited layer, by the fact that $Cu(hfac)_2$ formed in the disproportionation reaction reacts with hydrogen and reduces ions. bivalents to metallic copper:

$$Cu^{2+}\ (hfac)_2 + H_2 \rightarrow Cu^0 + 2\ H(hfac) \quad (3)$$

Some authors have pointed out that the addition of water vapor in the reaction chamber can lead to an increase in the deposition rate, water having a catalytic role (Vezin *et al*., 2002). The principle diagram of the copper deposition installation by the LCVD method is presented in Fig. 4.

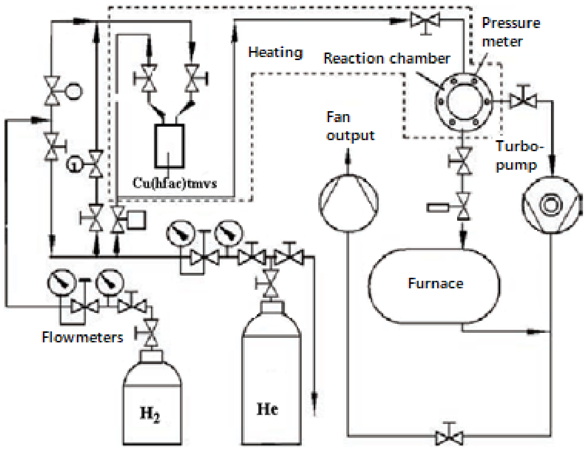

Fig. 4 – Scheme of the gas release and transport system for copper deposition (Vezin *et al.*, 2002).

Because this precursor for copper deposition has a much lower vapor pressure at room temperature than $Ni(CO)_4$ (1.3 mbar compared to 533 mb) it is very safe and easy to handle. In addition, it is not as dangerous to health as $Ni(CO)_4$ which is very toxic and carcinogenic. Two carrier gases, helium and hydrogen, were tested. The morphology and chemical composition of the deposited interconnections were analyzed by atomic force microscopy, optical microscopy, analysis of laser ionized microprobes (LIMA) and electrical measurements (Becker, 2008). The gas handling system releases a flow controlled by the organometallic precursor and transports the gas to the reaction chamber, where it is introduced through stainless steel injection needles located in the immediate vicinity of the upper surface of the chip. This system leads to much better results in quality than in static working conditions (when the gas does not flow), because the fresh precursor flows continuously to the laser heated spot. The reaction chamber was also electrically powered so that it was possible to successfully measure the deposition even during the process.

Prior to deposition, the reaction chamber was evacuated to the air with a turbomolecular pump to a pressure of 10^{-4} mbar. During deposition the bottle of Cu(hfac)tmvs liquid is heated to 36°C to increase the vapor pressure to 0.33 mbar. To avoid condensation in the transport pipes and the reaction chamber were heated to 38°C and 40°C respectively.

The precursor and carrier gas (He or H_2) were checked with flow meters, setting the flow at 2 cm^3/min and kept constant (Remes, 2006). The unreacted precursor and reaction by-products were burned in an furnace. An Ar^+ laser at wavelengths of 488 and 516 nm was used. The beam was amplified 5 times and collimated before reaching the microscope objective (focal length f = 20 mm and numerical aperture NA = 0.28). The beam enters the reaction chamber through a quartz window. The LCVD process was monitored in real time by a coaxial video system and a digital image processor.

6. Conclusions

The LCVD method applied for nickel and copper deposition was used to process several hundred prototype editing and repair systems. These applications referred to: rewriting of signal lines, test samples for establishing the deposition path, shielding and electrical voltage for the deposition of supply lines. These studies have shown that the LCVD method and laser cutting can be effective methods in the repair and restructuring of integrated circuits (IC), especially when rewriting (reconditioning) of longer distance circuits is required.

The LCVD method of nickel deposition using $Ni(CO)_4$ as a precursor was analyzed as a function of the precursor partial pressure and the $Ni(CO)_4/He$ dilution ratio. It was found that the dilution of the helium precursor leads to the intensification of the deposition and the improvement of the morphology of the deposited layer in the CI reconditioning works.

The LCVD method of copper deposition using Cu(hfac)tmvs as a precursor for IC repair works was applied using either Helium or Hydrogen as the diluent gas. In the case of helium use the deposition rate is lower and the deposited film is not uniform, while in the case of hydrogen use the velocity is almost double, the deposited film is uniform and the deposit resistivity is low, much lower than that of nickel. Heating the precursor and the carrier gas in the reaction zone is beneficial.

The low toxicity of Cu(hfac)tmvs, the superior quality of the deposited lines and their lower resistivity, make it more feasible to use copper deposits to the detriment of nickel deposits for practical CI editing work.

The LCVD technique is still in the phase of intense research and the limit of possibilities of use has not yet been reached. Further progress depends on superior laser development and finding suitable, high-power, high-focus lasers.

Although a large number of materials and deposition methods have been studied, the basic mechanism is still not well understood. The dynamics of the precursor gas reaction on the surface, the interface phenomena, the mechanism of multicomponent deposition and the role of various laser parameters in the growth of the deposited film have not yet been fully investigated.

This technique is growing in importance due to the multiple applications in microelectronics and in the production of integrated circuits with very high part density. Due to the possible applications in microsurface deposition, doping and etching possibilities have been realized various device structures, such as super grids, three-dimensional network structures, gate networks, reorganization of masks (templates) for integrated circuits.

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STUDIU PRIVIND REALIZAREA CIRCUITELOR INTEGRATE PRIN TEHNICA LCVD

(Rezumat)

Lucrarea prezintă o sinteză a metodei tip LCVD (Laser-induced Chemical Vapor Deposition) utilizată pentru obținerea completă a unui circuit integrat prin depunerea de filme subțiri pe cale chimică din fază de vapori, CVD (Chemicav Vapor Deposition). În lucrare sunt analizate atât mecanismul pirolitic al metodelor cât și depunerea de Ni și Cu folosind precursori de tipul $Ni(CO)_4$ și Cu(hfac)tmvs (cupru hexafluoroacetilacetonat trimetilvinilsilan). S-au analizat metodele de depunere din punct de vedere teoretic studiind dinamica reacției gazului precursor pe suprafață, fenomenele de la interfață, mecanismul depunerii multicomponente și rolul diverșilor parametri ai laserului în creșterea filmului depus din punct de vedere al utilizării practice și al toxicității substanțelor utilizate în procesul de depunere.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 65 (69), Numărul 1-4, 2019
Secţia
ŞTIINŢA ŞI INGINERIA MATERIALELOR

PROFESIONAL EXPOSURE TO CARBON DIOXIDE AND INHALABLE POWDERS AT THE WORKERS FROM THE ZOOTECHNICAL FARMS FOR SUINES RISING FROM THE COUNTIES OF IAŞI AND NEAMŢ

BY

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Received: November 1, 2019
Accepted for publication: December 19, 2019

Abstract. The study presented in this paper discusses the case of professional exposure at atmospheric agents namely carbon dioxide and inhalable powders in zoo technic field, precisely inside the halls for suines rising. There have been measured the levels of the two pollution factors in different locations, in different farms from two counties of Moldova, Iași and Neamț, halls characterized by specific technological parameters for growing youth, mature, boars and sows. After processing the collected data and interpretation of the results there have been drawn conclusions and formulated precise recommendations concerning the enhancing of the degree of safety of workers in this field.

Keywords: equipment reliability; air pollution; objective and subjective cause of an event; faulty bearing slack; fatigue limit; tension adjustment.

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1. Introduction

The workers on zoo technical farms of suins rising are exposed to occupational risks of various types: mechanical risks (hits, stings, animal bites), physical risks (noise, extreme temperatures, powders), chemical risks (toxic gas exposure – carbon dioxide, ammonia, endotoxins), biological risks (allergies, zoonosis).

The monitoring of respiratory noxes, with an accent on the carbon dioxide and inhalable powders (with an aerodynamic diameter less than 100 µm) has a double signification and applicability both from the perspective of occupational hygiene (ensuring the health of workers in the zoo technical field), as well as from the perspective of veterinary medicine (a good state of health of farm animals (Cornoiu, 2013)).

2. Material and Method

In seven zoo technical farms for suins rising from the counties of Iași and Neamț there have been done, during 3 years (2013, 2014, 2015), a series of 89 simultaneous determinations of carbon dioxide and inhalable powders, taking into account the specific conditions of various working points (generated by the age, degree of agglomeration and the metabolic necessities of animals – young, grown up, boars and sows).

The concentration of carbon dioxide was determined using a multi-gas detector, Drager type, with a carbon dioxide special sensor and with a Drager pump (Accuro), with calorimetric tubes for short term operation, specific for carbon dioxide, Fig. 1.

Fig. 1 – Accuro pump – left; Drager type multi-gas detector – right
(https://www.draeger.com/en-us_us/Products/X-am-2500;
https://www.draeger.com/en-us/SearchResults?s=Dr%C3%A4ger+Accuro%C2%AE).
https://www.draeger.com/Products/Content/tubes-accuro-pump-pi-en-us.pdf

The inhalable powders have been prelevated by aspiration with a fix pump and deposition on fiber glass filters that were subsequently analyzed by weighting, Fig. 2.

Fig. 2 – Equipment for inhalable particles prelevation.

The equipment for prelevation and measuring both for gas and powders have been placed inside each hall of the farm, avoiding the direct exposure to sun light and the vicinity with the ventilation ports, at a height on 0.8 m from the ground (considered as the maximum respiratory level for the animals and for the workers in a bent position – the most intense from the point of view of the effort and the less favorable as exposing) Fig. 3.

Fig. 3 – Working position – less favorable for respiration.

For the evaluation of the risk of exposure for the zoo technic workers to powders and carbon dioxide, the values obtained from the measurements were compared with the professional exposure limit values (VLEP) existent in the profile legislation in force (Ghid de securitate și sănătate în muncă, 2013):

VLEP Carbon dioxide = 5000 ppm
VLEP Inhalable powders = 10 mg/m^3

The mathematical processing of data obtained by measurements was done by calculating the parameters: average ± standard deviation.

For each value it was calculated the variation coefficient (homogeneity), that under the level 30-35% characterizes a homogenous series of determinations an over this threshold it is attributed to a heterogeneous series, with large variations and great distance between extremes:

$$CV = \frac{\sigma}{\overline{x}}[100]$$

σ – standard deviation; *CV* – variation coefficient.

3. Results and Discussion

After prelevation and computing the values were concentrated in the shape shown in Table 1.

Table 1
Values Determined at Farms for the Concentration of CO_2, [ppm] and Concentration of Inhalable Powders, [mg/m^3]

Farm	No of simultaneous determinations (CO_2 + inhalable powders)	Concentration CO_2, ppm (x ±σ)	Variation coefficient of values	Concentration of inhalable powders, mg/m^3 (x ±σ)	Variation coefficient of values
A	11	555 ± 90.1	16%	4.1 ± 2.1	51%
B	21	555.6 ± 83.7	15%	4.2 ± 2.0	48%
C	10	549.4 ± 83.9	15%	4.0 ± 1.7	43%
D	38	564.2 ± 82.9	15%	3.7 ± 1.4	38%
E	4	512.5 ± 115.7	23%	4.1 ± 2.3	56%
F	3	466.6 ± 152.8	33%	2.5 ± 1.7	70%
G	2	550.0 ± 70.7	13%	3.9 ± 1.0	26%

I. The values of the CO_2 concentration o in the atmosphere of the zoo technical halls, for all the 89 determinations, varied between a minimum of 300 ppm to a maximum of 650 ppm, with a total average 555.05 ± 83.44 ppm with a variation coefficient of 15.03%.

Comments
I.1 The level of CO_2 concentration did not overcome the professional exposure limit values (VLEP) – 5000 ppm at no determination;
I.2 The series of determination is homogenous and this characterizes a well controlled level of CO_2 concentration in all of the halls, no matter the specific of those and season atmospheric factors.

II. The level of inhalable powders varies in a wide range between 0.5 and 9.5 mg/m^3, with an average of 4.296 ± 2.00 and o variation coefficient of 46.55%.

Comments
II.1. The values are under the professional exposure limit values (VLEP) – 10 mg/m^3 with top values close to the admissible limit.
II.2 The series of is heterogeneous, some locations grouping various conditions, subsequently they can be attributed to internal factors that generate powders to some specific zoo technic halls.

4. Conclusions and Recommendations

By comparing the values determined for the concentration of CO_2 and respectively of inhalable powders inside zoological halls for pig farming with the admissible values imposed by the legislation in force concerning the occupational hygiene, we can consider, for both noxes, an acceptable level of exposure that do not generates risks on the state of health of the workers in the evaluated units.

Because the existence of some values near to the maximum exposure limit, imposed by the legislation in force for the inhalable powders, it is necessary to identify the sources that generate powders in the respective locations and also to implement monitoring programs and intervention measures for diminishing these values and bringing them in a range of more significant safety.

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https://www.draeger.com/en-us_us/Products/X-am-2500
https://www.draeger.com/en-us_us/SearchResults?s=Dr%C3%A4ger+Accuro% C2%AE
https://www.draeger.com/Products/Content/tubes-accuro-pump-pi-en-us.pdf

EXPUNEREA PROFESIONALĂ LA DIOXID DE CARBON ȘI PULBERI INHALABILE LA ANGAJAŢII DIN FERME ZOOTEHNICE DE PORCINE DIN JUDEȚELE IAȘI ȘI NEAMȚ

(Rezumat)

Studiul prezentat în această lucrare discută cazul expunerii profesionale la agenţi atmosferici și anume bioxid de carbon și pulberi inhalabile în domeniul zootehnic, concret în interiorul halelor de creștere a suinelor. Au fost realizate măsurători ale nivelurilor acestor doi factori de poluare atmosferică în diferite locații, în ferme diferite, din două județe ale Moldovei, Iași și Neamț, hale caracterizate de parametri tehnologici specifici creșterii tineretului, maturilor, vierilor și femelelor. După prelucrarea valorilor măsurate și interpretarea rezultatelor au fost trase concluzii și au fost formulate recomandări precise privind creșterea gradului de siguranță a locurilor de muncă din acest domeniu.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 65 (69), Numărul 1-4, 2019
Secţia
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BARRIER BETWEEN DANGER AND RISK

BY

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Received: November 1, 2019
Accepted for publication: December 19, 2019

Abstract. An assessment paper that includes dangers instead of risks will implicitly lead to the development of a prevention plan that is not applicable by the employer. The need to establish a barrier between danger (intrinsic property of the technology to cause damage) and risk (non-conformities found in the workplace which in interaction with the worker can lead to injury) is real in order to hand over to the employer an applicable assessment work, in order to achieve secure jobs. The paper gives examples that enable to easier make the difference between risk and danger and also puts into discussion some of the motives that lead to such confusions and thus to low quality work in the field of risk assessment. By means of a causal tree the motive of the employer for not rejecting a low quality work about risk assessment is also revealed.

Keywords: risk assessment; causal tree method; level of risk; level of security; dangerous situation.

1. Introduction

Law 319/2006 on safety and health at work states in art. 13 “In order to ensure the conditions of safety and health at work and to prevent accidents at work and occupational diseases, employers have the following obligations”.

Among these obligations at paragraph b) the law specifies:

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"b) to draw up a prevention and protection plan composed of technical, sanitary, organizational and other measures, based on the risk assessment, which to apply according to the, working conditions specific to the unit".

Making a prevention and protection plan for a certain enterprise is a complex task that involves some specific steps indicated in the literature (Darabont *et al*., 2001; Moraru *et al*., 2014).

2. Presenting Facts and Formulating the Problem

As can be seen, according to the legislation, the measures in the prevention plan depend directly on the assessor's ability to differentiate between a danger and a risk.

A prevention plan in which 90% of the actions are permanent means, for a specialist that the evaluation includes 90% hazards and not risks, and of course the lack of experience of the assessor who did such a plan.

How would someone feel if one day he or she learns that his or her life partner, who is a dentist and works in a state-of-the-art office, came home and told that she/he had been presented with an evaluation paper with 79 risks? of which 59 with maximum severity (death).

That person would be entitled to be very worried about his or her partner of life and would go so far as to make him or her change the job even this is not so easy to do.

In such a situation an another idea come naturally: verifying the documents. Looking through the papers one can found that most of the risks with maximum severity had a very low frequency, *i.e*. "never alive". After this, one can really calmed down realizing that, in fact, that assessment included dangers, which were very well controlled by protective barriers imposed by the equipment manufacturer and not real risks.

By the nature of the service, and working a lot with subcontractors who are obliged to present me risk assessments for the works to be performed in our facilities, I noticed that these documentations are performed in a general manner, the evaluator taking into account the dangers of the technology and not the actual risks on the ground.

Another finding, related to the insertion of dangers in the evaluation documentation, starts from the evaluator's fear (or lack of experience) of not omitting certain risks. So even if there is no evidence about the existence of a risk, the inexperienced assessor includes it in the documentation.

More over, an assessment paper that includes measures only for level 3 and above risks means that level 1 and 2 risks are considered more dangers than risks.

3. Identifying the Causes

Someone could wondered: how I could differentiate between a danger and a risk in order to identify correctly the possibilities of injury before they occur but also not to load the documentation with risks that have no real basis.

If one starts from the definition of danger "the intrinsic property of the elements (working materials, energy sources, technical equipment, working environment, methods, practices and working technologies) to cause unwanted events or damage (accidents, diseases and material damage)" (Pece, 2003) - photo 1 and risk "the combination of the probability and severity of an injury or attack on health that may occur in a dangerous situation" (Pece, 2003) - photo 2, Fig. 1.

Photo 1 Photo 2

Fig. 1 – Danger – photo 1; risk – photo 2.

If the phrase "dangerous situation" which actually means a non-compliance that can lead with a certain frequency and severity to an accident is by mistake confused with "danger", then the assessment work will include many dangers and not dangerous situations.

The assessment that is performed is always an a priori assessment defined as "a deductive, hypothetical process, in which, taking into account existing risk factors (dangerous situations), we imagine conditions and phenomena with the probability of occurring events that result in accidents at work or occupational diseases" (Moraru, 2010).

So: – it is a deductive process "in which we start from the identification of existing risk factors" identifiable by address (where? at what equipment? at what stage of intervention? or at what stage of operation?) and what is the non-compliance (deviation);

– after which we imagine "conditions and phenomena" (what can happen?) or how can affect the action found the worker (accident or illness).

The first cause that leads to the highlighting of the danger in the assessment works and not of the risks is the fact that one does not start from an identified concrete deviation but from an imaginary, general deviation.

Example: “the possibility of high pressure steam losses in an installation” - photo 3 is a danger but when it is specified that at “power supply pump no. 3 in the engine room there is a loss of high pressure steam” we are dealing with an identified risk - photo 4, Fig. 2.

Photo 3

Photo 4

Fig. 2 – Danger – photo 3; risk – photo 4.

Photo 5 – risk

Photo 6 – danger

Fig. 3 – Left side electrical installation without protection – risk – photo 5; right side the same installation with protection - danger – photo 6.

The second reason, one does not take into account the possibility of interaction between the danger and the worker, the condition needed for turning a danger into a risk.

Example: an electrical installation without protection is a risk - photo 5 but, if it is provided with a protection barrier and with an automatic disconnection system when removing it, it will never present a risk of electric shock - photo 6, for workers passing through the area, because they cannot come into contact with live parts - so there is a potential danger but not a risk, Fig. 3.

The third reason is the acceptance of poor quality evaluation works by the beneficiary. An analysis for this last case is made by the causal tree method and shown in Fig. 4.

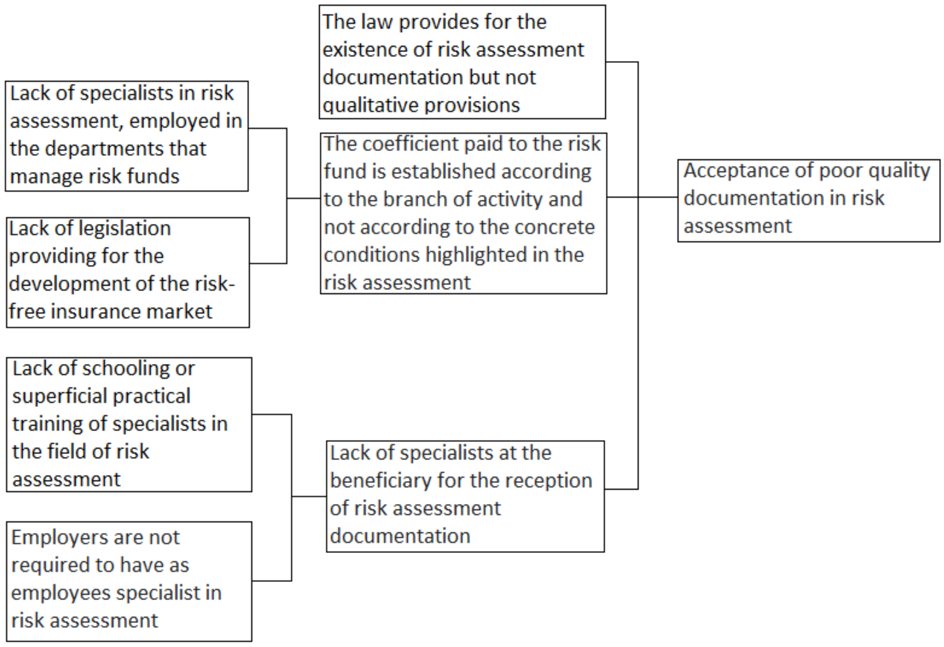

Fig. 4 – Possible causal tree for acceptance of poor quality documentation in risk assessment.

The following conclusions can be drawn from the causal tree:

1. The assessment of the level of risk can be for some employers an expensive document and for this reason it is only updated when an accident occurs;

2. It is not considered a document that needs to be worked on and constantly updated because many beneficiaries do not have specialized staff to do so;

3. The determination of the coefficient of payment to the risk fund does not take into account either the number of accidents or the assessments made, taking into account only the inclusion in the Romanian "CAEN" code.

4. Conclusions

If we want to raise the quality of risk assessment works, it should contribute to achieving financial savings for the employer and this can be done through two things:

1. Changing legislation and developing a free market for risk insurance;

2. Application of the first variant of Law no. 346/2002 which stated that “the establishment of the coefficient of contribution to the risk fund is made according to the number of accidents at work registered by an employer and the level of risk resulting and accepted from an evaluation work”.

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BARIERA DINTRE PERICOL ȘI RISC

(Rezumat)

O lucrare de evaluare în care sunt cuprinse pericole în loc de riscuri va duce implicit la realizarea unui plan de prevenire neaplicabil de către angajator. Necesitatea de a stabili o barieră între pericol (propietate intrisecă tehnologiei de a produce daune) și risc (neconformități constatate la locul de muncă, care în interacțiune cu lucrătorul pot să ducă la accidentarea acestuia) este reală având în vedere cerinţa obligatorie de a pune la dispoziţie către angajator a unei lucrăi de evaluare a riscurilor aplicabilă și prin urmare a obţinerii unei anumite securităţi a locurilor de muncă. Lucrarea oferă exemple care să facă mai uşoară diferenţierea între pericol şi risc şi de asemeni pune în discuţie motivele care conduc la astfel de confuzii în domeniul activității de evaluare a riscurilor. Pe baza metodei arborelui cauzelor este arătat un motiv plauzibil pentru care angajatorul nu respinge o documentaţie de evaluare a riscurilor de slabă calitate.

BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 65 (69), Numărul 1-4, 2019
Secţia
ŞTIINŢA ŞI INGINERIA MATERIALELOR

CONSIDERATIONS ON MIGRATION FROM BS OHSAS 18001:2007 TO ISO 45001:2018 IN THE CONTEXT OF INTEGRATED MANAGEMENT SYSTEM

BY

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Received: November 1, 2019
Accepted for publication: December 19, 2019

Abstract. The referential documents used for implementation of an Occupational Health and Safety (OHS) management system evolved from guidelines and national standards to ISO 45001:2018, an international standard aligned and interconnected with other international standards on management systems, allowing the companies to easily implement an integrated management system. The paper presents considerations on migration from BS OHSAS 18001:2007 to ISO 45001:2018 in the context of an integrated management system (*e.g.* quality – environmental – OHS) aimed to facilitate and optimise the process of transition.

Keywords: occupational health and safety; management systems; occupational health and safety audit.

1. Evolution of the OHS Management Systems

The concept of OHS management system has its origin in the quality domain and the approach of this system should be made in the context of its relation with the others management systems from which it has evolved, respectively quality and environmental management systems (Hoyle, 2005).

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The first referential documents on quality date from 1942 – 1952 and were used in USA in military domain, focusing on quality inspection. Between 1959 and 1968 in USA and UK appear the first standards on quality management, such as MIL-Q-9858, AvP92 and AQAP-1. Initially, they were intended for military domain, but then the concepts were extended to civil domain with the advent, in 1971, of ANSI Z 1.8/1971 standard, elaborated by the American Society of Quality (ASQ) and BS 9000 standard, elaborated by British Standard Institution (BSI) and intended for electronic industry (Darabont, 2010).

Between 1972 and 1987 a series of British standards appears in the quality assurance domain. The most important of them is BS 5750:1987 because it is introducing the requirement for auditing the implemented management system and, also, it represents the base on which International Organization for Standardisation (ISO) elaborates the ISO 9000:1987 series, the first version of the international standard in the quality domain (Darabont, 2010). The series of ISO 9000 continues with 1994 version, ISO 9001:2000, ISO 9001:2008 and ISO 9001:2015, the latest version of the standard.

Environmental management system referential documents evolved in a similar way as quality management referential documents, from national guidelines and standards to an international standard. In 3-14 June 1992, at Rio de Janeiro in Brazil, took place the United Nations Conference on Environment and Development which brought together representatives from 179 states and focused on the impact of human socio-economic activities on the environment. As a result of growing concerns for this issue, a series of national and regional standards appears in this time. These standards, together with the British standard BS 7750:1994 "*Specification for environmental management systems*" represented the base of elaboration of the first version of the international standard ISO 14001:1996 "*Environmental management systems. Specification with guidance for use*" (Darabont *et al*., 2017). The series continues with ISO 14001:2004 and ISO 14001:2015, the latest version of the standard.

The referential documents for OHS management system evolved in the same way as the quality and environmental ones, from different national guidelines and standards to an international standard. Thus, in 1991, the Health and Safety Executive (HSE) published *Successful Health and Safety Management – HS(G)65*, which describes the key elements of a successful health and safety management system, namely: policy, organising, planning and implementing, measuring, audit and reviewing performance (POPMAR) and the relationship between them (Gay and New, 1999). Another important moment is represented by the apparition of the BSI standard BS 8800:1996 "*Guide to occupational health and safety management systems*" which played the role of a guidelines for implementing and integration of OHS management system into the company's general management system, but its recommendations are not intended yet for certification purposes (Darabont, 2010). During this time, as an effect of the lack of an international standard, numerous national standards and guidelines appear, such as:

– UNE 81900:1996 EX "*Prevention of occupational risks. General rules for implementation of an occupational safety and health management system (O.S.H.M.S.)*" from a series of experimental standards elaborated by the AENOR (Spain) and withdrawn in 2004;

– "*Occupational Health and Risk Management System (OHRIS)*", developed in 1996 by the Bavarian State Government together with companies and trade associations to further improve occupational health and safety in companies and make them more economical. The series was continued by the Bavarian State Ministry for Family, Labour and Social Affairs with OHRIS:2018 (Bavarian State Government, 2018);

– AS/NZS 4801:2001 "*Occupational health and safety management systems - Specification with guidance for use*" and AS/NZS 4804:2001 "*Occupational health and safety management systems - General guidelines on principles, systems and supporting techniques*", Australian and New Zealand standards;

– AFS 2001:1 "*Systematic Work Environment Management*" elaborated in 2001 by the Swedish Work Environment Authority;

– "*Construction Industry Occupational Health and Safety Management Systems (COHSMS)*", elaborated in 1999 by the Japan Construction Safety and Health Association (JCSHA).

In 1999, BSI elaborated OHSAS 18001:1999 "*Occupational health and safety management systems. Specification*", which had not yet the value of a standard, followed by its implementation guidelines, OHSAS 18002:2000.

Whilst the proposals to develop an international OHS management systems standard were rejected by the ISO Technical Management Board (TMB) twice, in 1997 and 2000, the International Labour Organisation (ILO) decided to elaborate the "*Guidelines on occupational safety and health management systems – ILO OSH 2001*", intended to be applied at national level or at organisational level (Darabont, 2010; Perry Johnson Consulting Inc., 2012; ILO, 2001).

In 2007, BSI published the standard BS OHSAS 18001:2007 "*Occupational health and safety management systems. Requirements*", marking the changing of this document from specification to standard. The standard was elaborated by the *OHSAS Project Group*, a consortium of 43 organisations from 28 countries (Praxiom Research Group Limited, 2018). Next year, the implementation guidelines appears as BS OHSAS 18002:2008 "*Occupational health and safety management systems. Guidelines for the implementation of OHSAS 18001:2007*". From now on, until the apparition of ISO 45001:2018, BS OHSAS 18001:2007 as a British standard, or transposed in national versions, will plays the role of an international standard, suitable for certification purpose and facilitating, together with ISO 9001 and ISO 14001, the implementation of an integrated quality – environmental – OHS (QEHS) management system. Romanian Standards Association (ASRO) transposed the BS OHSAS 18001:2007 as a Romanian standard, by SR OHSAS 18001:2008 and BS OHSAS 18002:2008 as SR OHSAS 18002:2009.

2. ISO 45001:2018 in the Context of Integrated QEHS Management System

Taking its place from BS OHSAS 18001:2007, the new standard ISO 45001:2018 "*Occupational health and safety management systems – Requirements with guidance for use*" represents an important reference, together with ISO 9001:2015 and ISO 14001:2015, to create an integrated QEHS management system at organization level as shown in Fig. 1 (Darabont *et al*., 2017a).

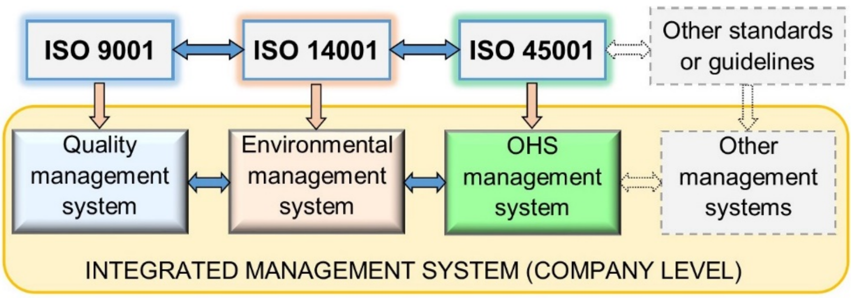

Fig. 1 – QEHS integrated management system.

In an integrated QEHS management system, the components (*e.g.* quality, environment and OHS) are interrelated, any failure in one components could produce significantly negative effects on others components. For example, a lack of operational control on trucks fleet of a chemicals transport company could lead to a traffic accident and generate, in the same time, an OHS issue (a work accident), an environmental problem (by spilling the chemicals) and a quality problem (an unsatisfied client) (Darabont *et al*., 2017b).

In order to facilitate the integration of different management systems at the company level and to optimize the control of different risks specific to one management systems which could have multiple negative effects not only on the management system to which they are specific, but also on the others, the standards such as ISO 9001, ISO 14001 or ISO 45001 were designed to have the same structure, defined by Annex SL elaborated by the ISO with the following main elements:

1. Scope
2. Normative references
3. Terms and definitions
4. Context of the organisation
5. Leadership

6. Planning
7. Support
8. Operation
9. Performance evaluation
10. Improvement.

As the management system standards have the same framework structure, the conflicts, duplication or confusion are avoided when developing, implementing, maintaining and auditing different management systems at the company level.

3. Comparison of BS OHSAS 18001:2007 and ISO 45001:2018

ISO 45001:2018 was published on 12th March 2018 and is established to totally replace the use of BS OHSAS 18001:2007 by March 2021. In Romania, the SR ISO 45001:2018 was published by ASRO on 20th April 2018, replacing the SR OHSAS 18001 and having a coexistence period until 31st March 2021.

The migration from BS OHSAS 18001:2007 to ISO 45001:2018 does not mean to build a new OHS management system from the beginning. There are similarities between the two standards, which allow to keep elements of the management system and its documentation, but also there are differences that should be addressed in the transition process.

Thus, both standards are intended to help organisations to create a coherent and efficient framework for managing OHS issues in order to prevent work accidents and occupational. Their fundamental principle is *Plan – Do – Check – Act* (PDCA) cycle, based on the following steps (Fig.2):

– *Plan* – determine and assess risks and opportunities, establishing OHS objectives and processes necessary to deliver the results in accordance with the organisation's OHS policy;

– *Do* – implement the processes;

– *Check* – monitoring and measuring the processes against OHS policy and objectives and report the results;

– *Act* – take actions to continually improve the OHS performance.

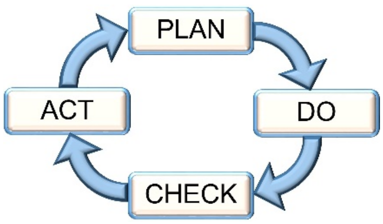

Fig. 2 – PDCA cycle.

Also, the standards have common elements, such as:

– the requirement for establishing an OHS policy and objectives;
– risk assessment;
– competence, training and awareness;
– internal and external communication;
– identifying and accessing the legal requirements;
– emergency preparedness and response;
– evaluation of compliance;
– internal audits;
– management review.

As it is elaborated on the high level structure provided by Annex SL, ISO 45001:2018 is easier to use than BS OHSAS 18001:2007 for an integrated management system together with other international standards on management systems elaborated on this annex, such as ISO 9001 and ISO 14001.

ISO 45001:2018 contains both requirements and guidance for use, while BS OHSAS 18001:2007 contains only requirements, guidelines being provided by BS OHSAS 18002:2008.

ISO 45001:2018 requires the organisation to define the context of organisation by considering both internal and external issues which could affect its capacity to achieve the established OHS objectives. Also, the term “document” and “record” from BS OHSAS 18001:2007 have been replaced with the term “documented information”, allowing organisation more flexibility in choosing the appropriate information extent, format (*e.g.* language, graphics) and media (*e.g.* paper, electronic on intranet or extranet).

ISO 45001:20018 defines more detailed than BS OHSAS 18001:2007 the role and responsibilities of top management. Even if both standards require the top management to take the overall responsibility for OHS, ISO 45001:2018 does not mention a management appointee for OHS management system and is more correlated with OHS legislation, such as Directive 89/391/EEC transposed in Romania by Law no.319/2006 on OHS and its applying methodological norm approved by Government Decision no.1425/2006, in aspects like:

– the overall responsibility and accountability of top management for the prevention of work-related injury and ill health and for providing safe and healthy workplaces and activities;
– ensuring the organisational framework and required resources for OHS;
– informing and training of the workers;
– consultation and participation of the workers;
– protecting workers from reprisals when reporting incidents, hazards, or risks;
– supporting the establishment and functioning of health and safety committees.

The clauses comparison of the two standards are presented in Table 1, as a useful instrument for determining which elements of the OHS management system could be kept and what new elements are needed when migrating from BS OHSAS 18001:2007 to ISO 45001:2018.

Table 1
Comparison of ISO 45001:2018 and BS OHSAS 18001:2007

ISO 45001:2018	BS OHSAS 18001:2007
Foreword	Foreword
Introduction 0.1 Background 0.2 Aim of an OH&S management system 0.3 Success factors 0.4 Plan-Do-Check-Act cycle 0.5 Contents of this document	Introduction
Occupational health and safety management systems — Requirements with guidance for use	Occupational health and safety management systems - Requirements
1 Scope	1 Scope
2 Normative references	2 Reference publications
3 Terms and definitions	3 Terms and definitions
4 Context of the organisation	-
4.1 Understanding the organisation and its context	-
4.2 Understanding the needs and expectations of workers and other interested parties	-
4.3 Determining the scope of the OH&S management system 4.4 OH&S management system	4 OHS management system requirements 4.1 General requirements
5 Leadership and worker participation 5.1 Leadership and commitment	4.4.1 Resources, roles, responsibility, accountability and authority
5.2 OH&S policy	4.2 OH&S policy
5.3 Organizational roles, responsibilities and authorities	4.4.1 Resources, roles, responsibility, accountability and authority
5.4 Consultation and participation of workers	4.4.3 Communication, participation and consultation 4.4.3.2 Participation and consultation
6 Planning	4.3 Planning
6.1 Actions to address risks and opportunities	-
6.1.1 General	-
6.1.2 Hazard identification and assessment of risks and opportunities 6.1.2.1 Hazard identification 6.1.2.2 Assessment of OH&S risks and other risks to the OH&S management	4.3.1 Hazard identification, risk assessment and determining controls

ISO 45001:2018	BS OHSAS 18001:2007
system	
6.1.2.3 Assessment of OH&S opportunities and other opportunities to the OH&S management system	-
6.1.3 Determination of legal requirements and other requirements	4.3.2 Legal and other requirements
6.1.4 Planning action	4.3.1 Hazard identification, risk assessment and determining controls
6.2 OH&S objectives and planning to achieve them	4.3.3 Objectives and programme(s)
6.2.1 OH&S objectives	
6.2.2 Planning to achieve OH&S objectives	
7 Support	-
7.1 Resources	4.4.1 Resources, roles, responsibility, accountability and authority
7.2 Competence	4.4.2 Competence, training and awareness
7.3 Awareness	
7.4 Communication	4.4.3 Communication, participation and consultation 4.4.3.1 Communication
7.4.1 General	
7.4.2 Internal communication	
7.4.3 External communication	
7.5 Documented information	4.4.4 Documentation
7.5.1 General	
7.5.2 Creating and updating	
7.5.3 Control of documented information	4.4.5 Control of documents 4.5.4 Control of records
8 Operation	4.4 Implementation and Operation
8.1 Operational planning and control	4.4.6 Operational control
8.1.1 General	
8.1.2 Eliminating hazards and reducing OH&S risks	4.3.1 Hazard identification, risk assessment and determining controls
8.1.3 Management of change	4.3.1 Hazard identification, risk assessment and determining controls 4.4.6 Operational control
8.1.4 Procurement	4.3.1 Hazard identification, risk assessment and determining controls 4.4.6 Operational control
8.1.4.1 General	
8.1.4.2 Contractors	
8.1.4.3 Outsourcing	
8.2 Emergency preparedness and response	4.4.7 Emergency preparedness and response
9 Performance evaluation	4.5 Checking
9.1 Monitoring, measurement, analysis and performance evaluation	4.5.1 Performance measurement and monitoring

ISO 45001:2018	BS OHSAS 18001:2007
9.1.1 General	
9.1.2 Evaluation of compliance	4.5.2 Evaluation of compliance
9.2 Internal audit	4.5.5 Internal audit
9.2.1 General	
9.2.2 Internal audit programme	
9.3 Management review	4.6 Management review
10 Improvement	4.6 Management review
10.1 General	
10.2 Incident, nonconformity and corrective action	4.5.3 Incident investigation, nonconformity, corrective action and preventive action 4.5.3.1 Incident investigation 4.5.3.2 Nonconformity, corrective action and preventive action
10.3 Continual improvement	4.6 Management review

4. Conclusion

The referential documents used for implementation of OHS management systems evolved from guidelines and national standards to ISO 45001:2018, an international standard aligned and interconnected with other international standards on management systems such as ISO 9001:2015 and ISO 14001:2015, allowing the companies to easily implement an integrated management system.

The importance of an integrated management system for a company is sustained by a series of reasons such as:

– elements regarding quality, environment or OHS are interrelated, so, for example, an issue on OHS could produce issues on quality and/or environment;

– an integrated management system allow the company to have a better control on different types of risks and to optimise the resources allocated for implementing and maintaining the management system.

The construction of an integrated management system (*e.g.* QEHS) is now facilitated by the availability of international standards ISO 9001, ISO 14001 and ISO 45001 designed to have the same structure, defined by Annex SL. Thus, conflicts, duplication or confusion are avoided in the developing, implementing, maintaining and auditing processes.

When migrating from BS OHSAS 18001:2007 to ISO 45001:2018 it should be considered that there are similarities between the two standards, which allow to keep elements of the management system and its documentation, but also there are differences that should be addressed in the transition process. The comparison of the two standards, presented in the paper, could be a useful instrument for determining which elements of the OHS management system could be kept and what new elements are needed in the migration process.

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CONSIDERAȚII PRIVIND TRANZIȚIA
DE LA BS OHSAS 18001:2007 LA ISO 45001:2018 ÎN CONTEXTUL UNUI SISTEM DE MANAGEMENT INTEGRAT

(Rezumat)

Referențialele utilizate pentru implementarea unui sistem de management al securității și sănătății în muncă (SSM) au evoluat de la ghiduri și standarde naționale la ISO 45001:2018, un standard internațional aliniat și interconectat cu alte standarde internaționale pentru sisteme de management, permițând companiilor să implementeze mai ușor un sistem de management integrat. Lucrarea prezintă considerații privind tranziția de la BS OHSAS 18001:2007 la ISO 45001:2018 în contextul unui sistem de management integrat (de exemplu, calitate – mediu – SSM), având ca scop optimizarea procesului de tranziție.