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USE OF ECOLOGICAL PARADIGM IN MATERIAL DEGRADATION ENGINEERING

Maria NICOLAE, Cristian DOBRESCU, Valeriu RUCAI, Avram NICOLAE
University POLITEHNICA of Bucharest, Romania
e-mail: cristiandobrescu@yahoo.com

ABSTRACT

The necessity to move from the conventional technical-technological paradigms to the ecological paradigm is perfectly justified. The degradation of materials is defined as a negative phenomenon, whose study should be extended as a new scientific branch, called material degradation engineering. The two types of life cycles of materials (products) are: the entropic cycle and the antientropic cycle (negentropic).

The three arguments conditioning the ecological paradigm to be analysed are:

- the law of unity of opposites;

- the impurification with inclusions is a technological dirtying process, included into the industrial ecology;

- the degradation adversely influences the capacity of durable material.

The paper work is structured in five chapters based mainly on chapters II, III and IV, as fallows: II. The need to use new knowledge paradigms in the material degradation engineering, III. Classification of the degradation processes, IV. Complex degradation in continuous casting plants (c.c.p.)

KEYWORDS: sustainable materials, ecological paradigm, degradation

1. Introduction

The process of finding modalities to maximize the performance in metalworking engineering must be currently designed and operationalized on the coordinates of two modern concepts (models) of evolution:

- global knowledge;
- durable and sustainable development of the society [1].

In a context like the one above, it becomes necessary for the metalworking engineer to investigate the interconditioning and interactions existing in the convergence zones of the following three systems:

- the social system – S.S. (the quality of life in relation to the socio-cultural needs);

- the natural-ecological system - N.E.S. (the quality of environment in relation to the prevention of environmental pollution);

- the technological system - T.S. (in connection with the qualitative maximization of the technological parameters of manufacturing and use of metal materials) [2].

The material degradation is the major process (phenomenon, event) that causes the material quality alteration throughout its lifecycle (l.c.). Degradation is a multisystem (inter- or intra-) process because: [3, 4]

- It directly determines the durability of materials and products, i.e. their social utility (S.S.);

- It influences the process of primary material transformation into secondary material (waste or residue), which are polluting substances (N.E.S.);

- It can have a negative effect on the quality of material manufacturing processes and the durability of the components used in the industrial equipment and plants (T.S.) [5].

The final quality of the manufactured materials mostly depends on the mechanism and kinetics of the processes within the outline of thermotechnological plants. In such a context, the material engineer is interested in:

- the degradation of metal melts caused by the impurification with inclusions, which can be: [6]
  - endogenous, generated by their own metallurgical phenomena;

– exogenous, generated by the interactions between the metallurgical melts and the construction components of the plant, such as the refractory lining made of ceramic materials;

- the degradation of plant components caused by the destructive interactions between the metallurgical melts and the equipment material.

The importance of knowing the degradation of materials derives also from the fact that it can penetrate the entire life cycle (Table 1).

Table1. *Succession of possible material degradation processes over the lifecycle (l.c.) phases*

Possible degradation during the designing activity	Possible degradation when providing resources	Possible degradation during the manufacture of metal materials		Possible degradation when using the materials	Possible degradation in the relationship with the environment
		Melting, casting and solidification	Solid metal processing		

On the other hand, it was found that the specialized interest in degradation occupies a very small area. Thus, we can deduct from the literature that: [7-10, 11]

∗ Currently, most research topics focus on improving the use performance and *less* on studying the degradation phenomena;

∗ Even when the degradation is investigated, the degradation in the use phase of the material is mostly considered.

Based on the above, the authors believe to be important be launch a new scientific sub-branch on the knowledge market.

The material degradation engineering studies the quality deterioration in the field of technological processes and materials, caused by the intersystem destructive interactions (even inter-phasically) developed throughout an anti-entropic life cycle.

There are two types of life cycles (l. c.): [5]

− the circular-linear cycle, whose simplified representation is shown in Figure 1; it is an entropic cycle, because the secondary materials disposal into the environment increases its entropy deposit;

− the circular-active cycle, whose representation is shown in Figure 2; it is a negentropic (anti-entropic) cycle, because the reintegration of secondary materials contributes to the preservation of the environmental negentropy deposit.

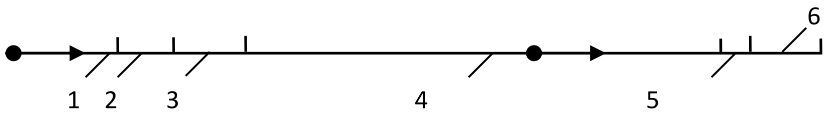

Fig. 1. *Schematisation of the life cycle of a metal product:*
1 - designing of the mechanical product; 2 - resource qualitative processing; 3 - product manufacture; 4 - use; 5 - removal from use; 6 - disposal of secondary materials (residues) into the environment.

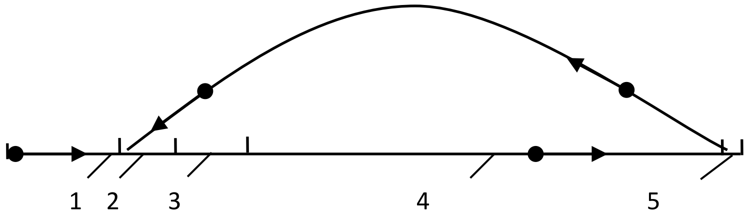

Fig. 2. *The phases of circular-active life cycles:*
1 - material designing; 2 - providing resources; 3 - manufacture; 4 - use; 5 - removal from use; 6 - 3R reintegration.

2. The need to use new knowledge paradigms in the material degradation engineering

In the field of defining, characterizing and designing of new ways of evolution in the field of materials, there is a need for a qualitative leap on a level of knowledge superior to the existing one. In the field of material knowledge, it becomes necessary to resort to new paradigm and methodology elements. More specifically, this means moving from the technical-technological paradigms to a new form of paradigm [12].

The ecological paradigm used in this paper as a vector of in-depth knowledge is considered to be a special paradigm, which is understood as a constellation of beliefs, values and methods within which the members of a community ask questions and give answers. In such a context, the event is investigated, identified, characterized and made available on methodological principles, methods and tools that highlight the priority importance of N.E.S. as a core system. More specifically, this means that the technological processes and the resulting materials are going through an anti-entropic life cycle (providing resources → manufacture → use → secondary material reintegration by using 3R technologies → disposal of residues [4].

The application of ecological paradigm to material engineering is based on three fundamental arguments [13, 14].

a) the law of unity of opposites acts dialectically in case of material manufacture and use. By applying this law, it can be stated that, in reality, the quality of a material life cycle is the result of two opposite events, as occurrence mechanism, and, in particular, as effect on the social sustainability of the material. The two events are generally considered to be:

∗ the efficient use, as a positive effect on the material durability; the maximization of this parameter requires the optimization of the use properties (also called technological properties or technical-functional properties);

∗ the degradation, having a negative effect on the durability of materials; the minimization of the effect of this event means optimizing the degradation properties (e.g. the minimization of the negative effect of corrosion claims the maximization of corrosion resistance).

The conflict between the efficient use and degradation can be optimized based on the lifecycle duration maximization, influencing the use and degradation parameters. There are a number of different situations concerning the causes acting upon them:

➢ material internal causes, aimed at preventing by reducing the factors that favour the degradation, i.e.:

– maximizing the use properties;

– maximizing the specific anti-degradation properties.

➢ material external causes, concerning the prevention or reduction of the intensity of the interactions between the material and environment, i.e.: [15-17]

– the manufacturing technological environment represented by the technological plants for steel-making – casting – rolling;

– the technological environment of material use;

– the environment.

➢ Conditions of reintegration through 3R technologies (recirculation, recycling, regeneration);

➢ Environmentally friendly storage of polluting residues.

b) Impurification of metal melts with inclusions can and must be analysed in the light of ecological paradigm. This assertion is supported by:

– Etymology, through the Latin origin (poluo - poluere), the term to pollute means to get dirty, to defile, and pollution can be interpreted as dirtying, a special form of impurification;

– The generation of inclusions in the melted steel is currently characterized as a dirtying phenomenon, which adversely affects the quality of material. [7]; we can speak about the technological pollution of the steel with inclusions;

– A similar situation is encountered in case of technological pollution of steel with tramp elements (Cu, Sn, Pb), caused by their transfer from scrap into the melt in the electric arc furnace.

c) The degradation adversely affects the function of durable material of the metal materials

The durable material – D.M. (sustainable material – S.M.) is the material that carries out simultaneously the functions of advanced material, efficient material, eco-material and socio-material, fulfilling in this way the rigours imposed by the three systems [14].

The advanced material, according to the ecological paradigm, is the material that goes through a full negentropic life cycle.

According to the technical-technological paradigm, the advanced material is the material that meets the rigours imposed by the advanced (top) industries. Based on this paradigm, the nuclear materials, for example, are advanced materials. According to the ecological paradigm, this function is not fulfilled because the material does not go through a negentropic life cycle, the nuclear waste being just disposed and not re-used.

The efficient material, according to the ecological paradigm, is the material which, going through an anti-entropic life cycle, ensures a maximum degree of recovery to the primary substance (intrinsic substance or native substance).

The primary substance is a necessary notion, because the cost-benefit analysis provides costs only for extraction, preparation, transport and handling, but not for the intrinsic value of the raw materials given by the content in the useful substance (e.g. the value of the main petroleum hydrocarbon) [18].

According to the technical-technological paradigm, the efficient material is the material whose use features reach maximum values. Judging by this paradigm, the nuclear materials are efficient materials. According to the ecological paradigm, this function is not fulfilled, since the nuclear residues, which still contain the primary substance, are not re-used.

3. Classification of the degradation processes

The authors believe there are several categories of degradation [13, 8], as follows:

a) depending on the life cycle phase, there are:

a.1) technological degradation caused by the degradation of processes occurring during the material manufacture; it can be also called process degradation or early degradation, because the degradation begins from the zero point of the life cycle.

a.2) use degradation.

b) depending on the determinants, there are:

b.1) objective degradation, caused by certain processes that cannot be avoided, but only reduced; in this category fall such examples:

– degradation caused by the metal melts impurification with inclusions and degradation caused by the destruction of ceramics by the melted steel - refractory ceramic lining interactions;

– metal corrosion in the environment or in the working environments, which exercise destructive actions [17].

b.2) subjective degradation, caused by the dysfunctions between the measures adopted in process designing and management (imposed specifications) and the actual operational conditions.

c) The complex degradation is the degradation involving multiple technical materials. It is the case of technological plants where the metallurgical melt interacts destructively with the construction components of the plant, resulting in the degradation of both phases.

4. Complex degradation in continuous casting plants (C.C.P.)

The processes occurring in the C.C.P. are the result of interactions between two main materials: molten steel and ceramic material of the refractory lining of the construction components:

The mechanism of degradation of the two materials consists of the phenomena described below, taking into account the notations shown in Figure 4.

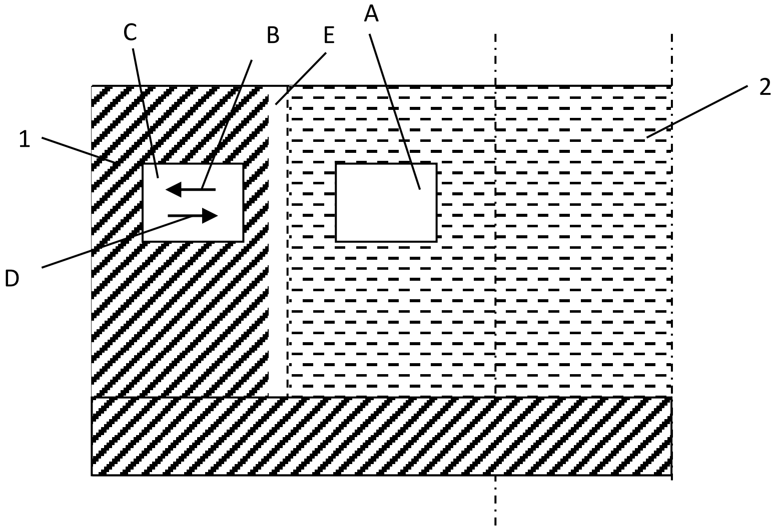

Fig. 4. *Schematization of metallurgical melt - ceramic material interaction processes. 1 - ceramic material; 2 - melted steel*

A) The interaction space is the area where the endogenous inclusions generation processes occur.

B) This is the area where exogenous inclusions generation processes occur. The phenomenon of ceramic material degradation begins here.

C) This is the area of penetration and physical-chemical interaction between the melt and the ceramic material. It is the actual process of ceramic material degradation.

D) This is the evacuation area of inclusions from the ceramic material of the refractory lining.

E) This is the area of possible adherence of the degradation interaction products. The metallurgical engineer is interested in two situations:

– deposits on the tundish refractory lining, a phenomenon leading to the formation of a pseudo-wear layer with degraded properties;

– deposits on the surface of the immersion tubes, which cause the clogging of the tubes, a phenomenon that adversely influences the steel casting properties [19, 20].

Three sub processes are occurring:

a) processes of adhesion to the melt - ceramic material interface. They are physical-chemical processes based mainly on wetting phenomena, which in turn dependent on the phase and interphase tensions. To study them, it is necessary to know the activation energy of the adhesion phenomena, $E_{a.a}$. They also depend on the shape (globular or polygonal cluster), as well as on the roughness of the inclusion surface, assessed through the roughness factor, r, [21, 16]. The latter influences the correlation:

$$\cos\theta_{s.r} = r\theta_{s.l} \tag{4.1}$$

where: $\theta_{s.r}$ is the interphase wetting angle of the rough surface, and $\theta_{s.l}$ is the interphase wetting angle of the smooth surface.

b) down flow processes. They are determined by the casting speed v_t, i.e. by the kinetic energy of the jet, $E_{c.j}$. In this case, the inclusions dissipate in the melt mass, where they are embedded by solidification.

c) processes for breaking the already-formed adhesion crust. In this case, the inclusion conglomerates dissipate in the mass of the melt, where they are embedded by solidification. $E_{c.j}$ plays a predominant role in this situation, too. Two situations can be met, depending on the values of the two energies [22].

- If $E_{a.a} > E_{c.j}$, the inclusions adhere to the ceramic lining and may cause unfavourable events (degradation of the wear layer of the lining or clogging of the tubes).
- If $E_{a.a} < E_{c.j}$, the inclusions decant into the melt, being driven by the flow. In this case, the inclusions dissipated inside the melt mass affect adversely the properties of the steel, determining the phenomenon of qualitative degradation of the material. Given that:

$$E_{c.j} = \frac{1}{2} m_i \cdot v_t^2 \tag{4.2}$$

and:

$$E_{a.a} = f(\alpha_{s-g};\ \alpha_{s-l};\ \alpha_{i-g};\ \alpha_{i-l};\ p_{top}) \tag{4.3}$$

where α represents the interphase tensions among the non-metallic inclusion, gas (from lining or as gaseous inclusion) and solid (ceramic material), and p_{top} is the melt pressure in the technological equipment, we deduce that the generation of inclusions and, implicitly, the phenomena of plant performance determination and steel degradation depend on two categories of factors:

– technological casting parameters;

– intrinsic characteristics of the materials involved in the phenomena.

5. Conclusions

- The study of material degradation should become a widespread and diverse area of knowledge called material degradation engineering.
- The complex degradation is an example of convergence between two branches (metal material engineering and ceramic material engineering).
- The ecological paradigm is becoming more important than the conventional paradigms, as it considers certain principles that take into account the importance of N.E.S. in interaction with the other systems.
- The ecological paradigm is based on three fundamental arguments:
  - the law of unity of opposites;
  - the impurification with inclusions is a technological dirtying process, included into the industrial ecology.

The degradation adversely influences the capacity of durable material.

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