Quantification of the wear according to different approaches to a Hard Alloy « Z38CDV5-3 »

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Abstract.*--The wear is defined as the material removal (earth) of the surface of an object by contact with another surface and not simply the deformation or the dislocation of the material of the workpiece in contact. The wear can be divided into two categories: Wear dominated by the majority by the mechanical behavior of materials and the wear caused by the chemical behavior of materials.There are seven mechanisms of mechanical wear listed; however, there are only three types of surface for the interaction of surface that may cause them: Sliding (a slide coating by report to another over long distances) The wear by rubbing (A surface oscillates on minute distances by report to the other) and erosion (solid particles) encroach on a single surface from an external source). For this document, only dry (non-lubricated) Sliding .Wear will be envisaged.The mechanisms of actual wear to dry sliding wear depends on a number of variables, including: surface finish, surface geometry of, the orientation, sliding speed, relative hardness (of a surface compared to the other or in relation to the abrasive particles between the surfaces), the microstructure of materials, and more. From these variables, it can be seen that the rate of wear is not a pure physical property and does not always occur in a uniform manner.*

Keywords: *Wear, Friction, Archard, Quantification, Hard Alloy, Surfaces, Contact, Deformation.*

1. Introduction

There are many types of wear. Each of these mechanisms is distinguished by its conditions of appearance and by its effects. All have in common, however, to be difficult to study of quantitative way, because it is necessary to be able to for this, distinguish what is own materials of the body in contact, which is clean to aspects structures (examples: their elastic properties, plastics, fatigue, their hardness, …). The same goes for the kinematic (geometry of surfaces and nature of the Movement) which gives rise to the thermomechanical fields responsible for wear. All these effects are more paired: The properties of materials are evolving with the load. For example, the softening modifies the ductility and the elastic limit. In addition, the geometries of contact, so the boundary conditions, evolve during the process of wear what constitutes an additional difficulty for the predictive calculation of the wear. The friction is itself very poorly known locally and microscopically because it is also evolving during the process of wear, especially because of the geometry of the contact, but also because of the debris trained.

In view of all these difficulties, it is understandable that the quantitative approaches are for the moment the very comprehensive macroscopic or to the image of the model of Archard and its derivatives. In the absence of forecasting tool, it often has recourse to experiments which attempt to reproduce the reality. The results obtained are only valid for the test considered and are often difficult to transpose in another context.
In this next paragraph, we will do a non-exhaustive list, models of wear given in the bibliography. We will strive to show the diversity of approaches to establish these models (energy approach, mechanical

approach, mathematical approach). Then we will present the models used specifically in the area of forging.

2. Identification of the Hard Alloy « Z38CDV5-3 »

COMPOSITION	PHYSICAL PROPERTIES	APPLICATIONS	QUALITIES
Carbon 0.40 Chromium 5.00 Molybdenum 3.00 Vanadium 0.50	* Density: 7.7 *Mean coefficient of expansion in m/m.°C: - between 20°C and 100°C: 11.0 x 10^{-6} - between 20°C and 300°C: 11.8 x 10^{-6} - between 20°C and 500°C: 12.8 x 10^{-6} - between 20°C and 700°C: 13.4 x 10^{-6} *Critical points: - Ac 1: 830°C - Ac 3: 885°C	- Inserts and punches for drop-stamping and forging. - Dies for light alloy die casting. - Extrusion tools.	- Good resistance to high temperature oxidation. - Low sensivity to thermal shock. - Excellent resistance to wear. - Excellent dimensional stability.

Tableau 1.Material's identification [1]

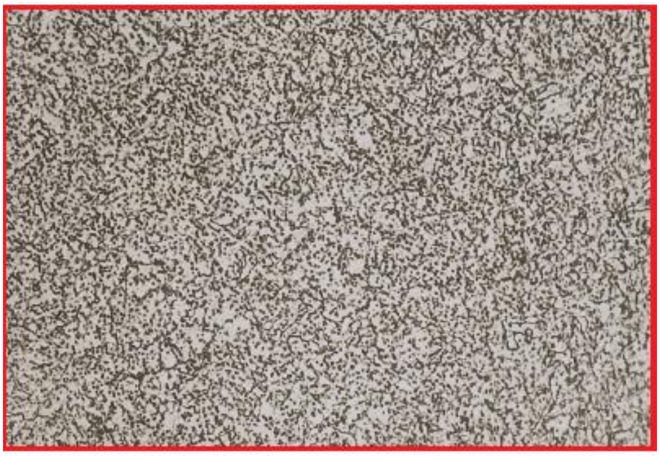

Figure1.Structure in the annealed condition
Correct structure (Mx500)

Brinell hardness approximately 235 in the softened condition.

Heat treatment[1]

Hardening:
- Preheat to 750°C
- Raise to 1010°C
- Air cool or gas pressure quench.

For large parts, air cooling may be replaced by quenching into a salt bath at 240°C, followed by cooling in air to room temperature.

It is recommended that heating should take place in a neutral atmosphere.

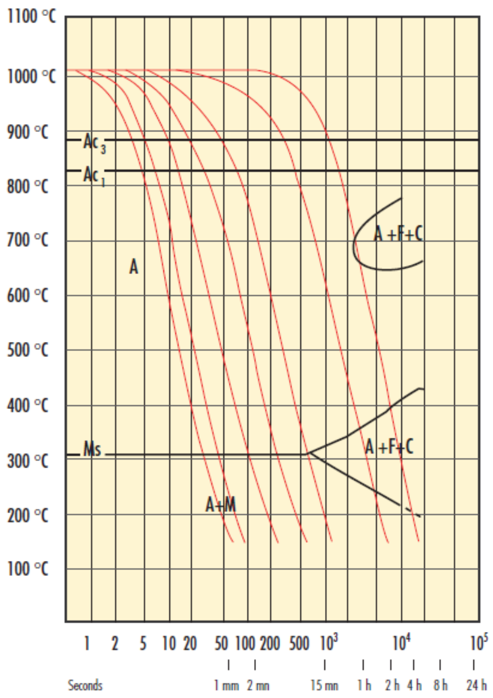

Figure2.CCT diagram Austenitizing at 1010°C

Tempering [1]**:**
- 1st temper at 550°C.
- 2nd temper between 550°C et 650°C according to hardness required.

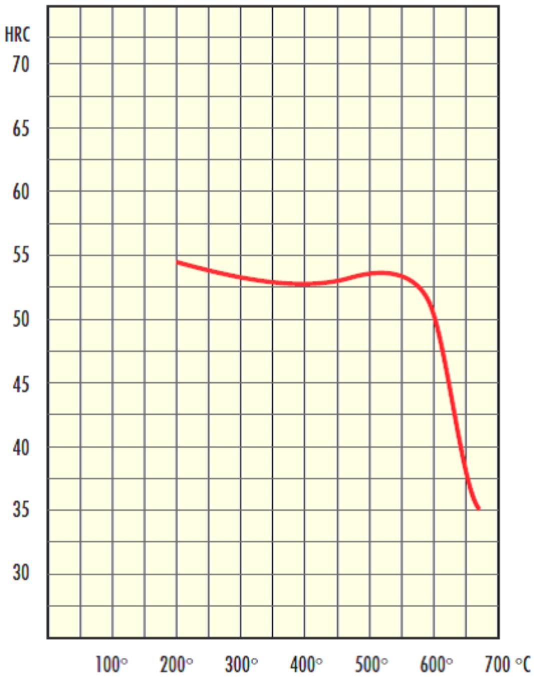

Figure3.Tempering curve (1 cm thick test piece)

Figure4.Structure after heat treatment
Correct structure (Mx500)

Mechanical properties

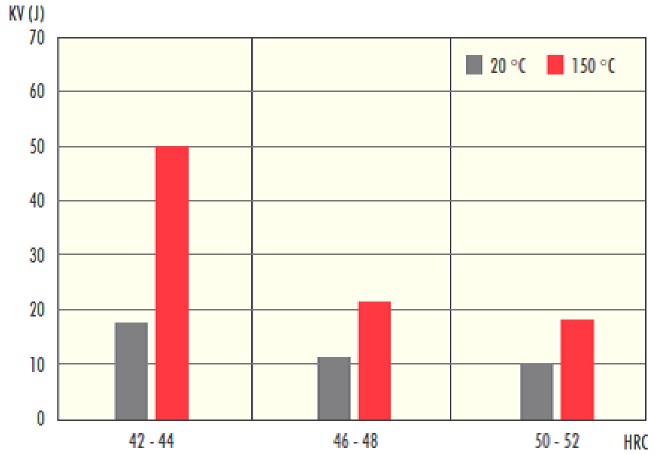

Figure5.Variation of impact strength with hardness for different working temperatures[1]

We recommended adequate preheating before commissioning the tools to increase their toughness.

Surface treatment

The material(Z38CDV5-3) is suitable for all nitriding processes.This treatment results in a hard surface layer providing improved resistance to erosion and wear. The hardness obtained after nitriding is of the order of 1000 Vickers [1].

3. Generic Laws

3.1 Classification of the models of wear [2]

The authors [1] have counted more than 300 laws relating to friction and wear over a period ranging from 1947 to 1992. They noticed that many of the laws are derived from the methods of the mechanics of solids including the properties of materials, the thermodynamic quantities or even of the variables assumed to be fundamental to the authors of these laws. They arrive at a chronological classification of these laws in three categories:

- the laws to empirical character have seen the day between the years 1950 and 1970. They take into account primarily of parameters relating to the conditions of the tests. It is impossible to transpose such laws to tests other than those for which they have been established.

- laws based on the mechanics of the contact emerged primarily between the Years 1970 and 1980. Some of them take into account the properties of the materials. One of the precursors of the more known is J.F. Archard [3] which defined the wear in the following manner:

$$W=ka\ d\ P/HB \qquad (1)$$

Where w is the lost volume expressed in m^3, KA a constant measured experimentally, the distance (m) travelled during the landslide, P is the applied load (N) and HB is the hardness of the material (N/m^2). The report p/ H_B introduces a grandeur that fact intervene the effects of structure (rough).
The simplicity of this model also reflects its limitations. For example, for a same torque of materials tested in different load and speed conditions, the coefficient of wear K_A can vary in a report 100.
- Finally, the laws based on the mechanisms of damage have developed since the
Years 1980. They include the mechanisms of dislocations, the fatigue properties the shear failure, …. Examples of these laws are presented in the following paragraph.

3.2 Overall Approach of wear

The approach of micromechanical analyzes of the interfaces is based on the thermodynamics of irreversible processes [4][5]. The authors consider the wear as a dissipative phenomenon, in order to establish, in a consistent theoretical framework, a criterion for the evolution of the mechanism of secondment of the particles. By placing themselves in the most general case, they apply the known laws of the mechanical (conservation of the Earth and of the quantity of movement, kinetic energy, 1st and 2nd Principle of Thermodynamics) to a set consisting of two bodies in contact and loser of the matter, in order to release a criterion of evolution of the Wear - criteria associated with a mobile border, the front of wear.
Figure.6 represents the system which are applied the basic laws of mechanics. It consists of three parts: two body in movement in relation to the other (S_1 and S_2), the third body (S_3) composed of particles of wear that came from the first two.
The interfaces I_1 and I_2 are the surfaces of discontinuity mobile and their movement defined the wear. Taking into account the flow of mass (S_1 to S_3on the one hand, and $S_2$to S_3On the other hand), are written sequentially for this system, the conservation of the Earth and of the quantity of movement, the theorem of the kinetic energy, as well as the first and second principles of thermodynamics. More specifically, the wear is defined by the energy dissipated at the borders I_1 and I_2, the consequences of the transfer of mass.

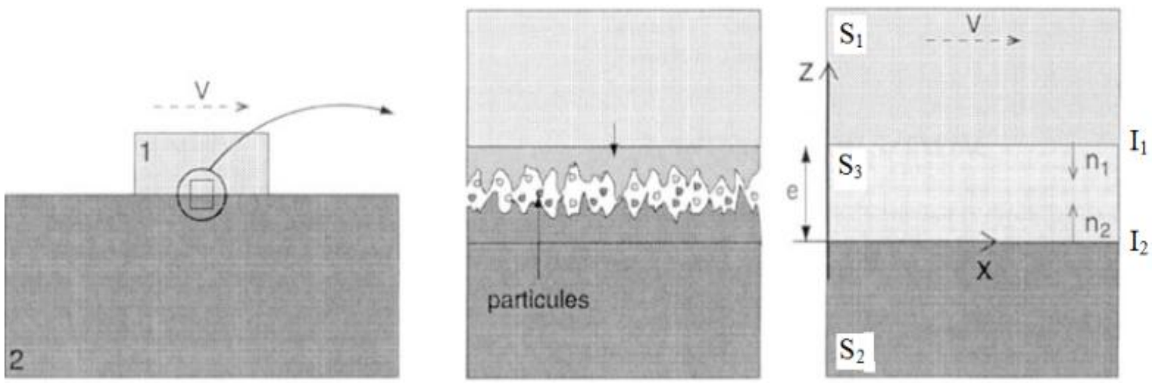

Figure.6: system of two bodies in contact and their interfaces [4].

The analysis leads to express the dissipation of energy in the S_3 interface from the three assumptions: the continuity of travel, normal efforts and the temperature at the borders II.
By thus assessing a refund rate of energy Ar (assimilated to a production of entropy) associated with the surface of discontinuity mobile II, a criterion of wear can be formulated in the following manner:

If EI < ES there is no wear
If Ei = ES there is potential wear

This model has been implemented by the following taking into account the behavior of the third body (analogous to a stream of particles or to a viscous solid) [6][7].
The proposed equations by this model can be resolved at the time by finite elements or analytical way. It can therefore be inserted into a code of calculation. It simply evaluates the loss of material (by soft wear) and the change of geometry from the essential parameters that are the speed of wear and the volume fraction of debris. The coefficient of friction, greatness important in tribology, but who sometimes varies making its modeling difficult, is not a given in the model. We can however infer from the normal constraints and local shear calculated.
This model has the advantage to be usable for any type of system with two body in contact in a situation of wear soft. It also allows to take into account the behavior of the third body, that it be made of particles, lubricant or a mixture of the two.
However, the proposed equations and the formalisms on which they are based, are proving quite heavy to implement.
Other authors [8][9] are also working on this type of approach based on the laws of thermodynamics: they consider the damage as a whole of irreversible processes (Wear, fracture).
To be consistent with the laws of thermodynamics, the irreversible process of damage must, monotonically, increase the entropy and decrease the thermodynamic energies. The irreversible processes dissipate the power supplied and this is reflected by the production of entropy. The authors make as well a model of degradation thermodynamics and show a good correlation between the normalized wear and the variation of entropy normalized. The Normalization divides each given to wear (or variation of entropy) at the time **t** by the value of the Wear (or variation of entropy) measured in 1 hour, in a configuration set. In the implementation of this model, the main difficulty is access to the micromechanical characteristics of the 3^{nd} body. Global studies of the wear have the advantage of not to focus on a mechanism of damage in particular.

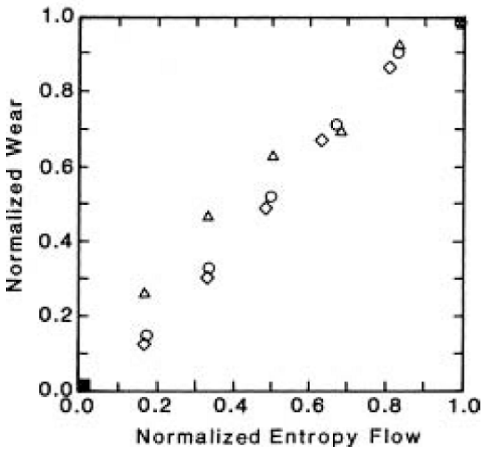

Figure.7: Wear standardized in function of the variation of entropy standardized, each point represents the average of 4 tests [9].

3.3 Energy Approach

The authors [10] consider that the Wear of Materials in contact not lubricated is a result of the energy dissipation due to friction. This is supported by the fact that the energy dissipated by friction may lead to a wear (cracking, plastic deformation, tribochemical reactions).
The mechanisms of wear are governed by the temperature of contact, the transformations of microstructure, the formation of films tribochemical, the welds of the surfaces in contact, or even the ruptures related to thermal and mechanical stress. The local increase of temperature and the loss of material in the friction track would result from the energy of friction dissipated in the area of contact.

The concept of power of friction dissipated by unit of surface, has been introduced by
Matveevsky as a measure of the level of heating by friction (energy expenditure) which take place in the area of contact of two surfaces " frottantes ". The temperature reached in the contact is directly related to the power of friction and to the geometry of the contact as well as the thermal conductivity of the body in contact. Qf is expressed in the form:

$$Qf = \mu \, P \, V / Ar \qquad (2)$$

With **μ** the coefficient of friction of Coulomb type, **P** the normal load (N), **v** sliding speed relative (m/s), and **Ar** the true area of contact (mm2). The power of friction expresses the amount of energy dissipated by friction in the contact zone, but does not take into account the time from which the energy is released to the materials in contact.
In place of the power of friction, Mohrbacher [11] is talking about the concept of cumulative energy dissipated, Ed, for the contact conditions of alternating friction (Fretting). Ed is calculated from the tangential force and loops of travel:

$$E_d = S \, F_t \, d \qquad (3)$$

With **Ft** the tangential force and the linear displacement (both measured during the test).
This approach has been used [12] to express the rate of wear in the form of volume of lost material per unit of energy dissipated (Figure.8) In the case of a unidirectional friction (ball on disk). From the

Figure 8, we can deduce the volume worn by unit of energy dissipated. This curve is interesting from a practical point of view because it allows the quantification and comparison of the wear resistance of different materials in the case of a unidirectional friction. In these conditions of unidirectional friction, they found:

$$Ed = \mu\ p\ v\ t \qquad (4)$$

With **t** the duration of the test. Mohrbacher [11] shows that there is a linear relationship between the dissipated energy and the volume worn. Olofsson [13] has also studied the dissipated energy during trials of micro oscillatory slip. As previously, there is a linear relationship between the dissipated energy per cycle of micro slip and the amplitude of movements.

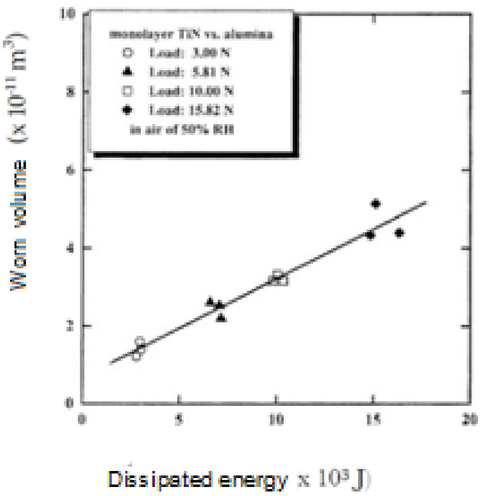

Figure.8: Wear in function of the dissipated energy accumulated in the case of a unidirectional friction of a ball on a disk under different loads [12].

Based on the model of soft wear by oxidation of T.F.J. Quinn, the authors have developed a new approach in which the constant of parabolic oxidation has been replaced by a oxidation kinetics linear. They consider that in these Conditions of tests (dry friction), the growth of the oxide is interrupted without ceases by flaking or ripping. As well, the rate of oxidation retains its initial value high. The model of Quinn taking into account a linear kinetics of oxidation for a pawn on disk is expressed in the form:

$$W = \frac{A_r\left[C_A \exp\left(-Q/RT_f\right)\right]}{f_0 \rho_0} t_g \qquad (5)$$

With **W** The volume worn, **Ar** the true area of contact, $\mathbf{F_0}$ the mass fraction of the oxide film in contact with oxygen, $\mathbf{r_0}$ the average density of oxides formed in the actual area of contact and $\mathbf{T_G}$ for

the slip time. $\mathbf{C_A}$ and **q** are, respectively, the constant of the Arrhenius and the activation energy of the oxidation, R the gas constant perfect, and $\mathbf{T_f}$ the flash temperature at the level of the contact.
In the mechanism of soft wear by oxidation, energy is dissipated by generation of heat, oxidation and removal of particles. According to the Equations (4) and (5) , the dissipated energy is related to μ, P, V. The expression proposed to calculate the temperature flash in the contact is Tf = C_Q μ V (P / hardness), where Q_C is a constant of proportionality. As well, the authors link the term C_A exp (-q / RTF) t to the dissipated energy E_d during the test.
For a couple of donated materials, the equation (5) takes the form:

$$W = \frac{A_r}{f_0 \rho_0} E_d \qquad (6)$$

This study puts forward a model of wear based on the energy dissipated in recital combinations of materials, environmental conditions and the aspects tribochemical.
However, the authors observe that with an increase in the load applied during their experimentation, the wear mechanisms change and they do not observe more of linearity between the dissipated energy and the volume worn: the model described thus depends on the operating conditions.

3.4 Approaches based on the model of Archard

3.4.1 Model of Archard based on identification of the thermal flows
Based on observations of degradation after over a hundred strikes of industrial matrices, the authors [14] Note of the abrasive wear, the crazing by thermal fatigue and a combination of the two following the localization of the Degradation on the matrix. The authors are attached to analyze the mechanisms of degradation by thermal fatigue pure. They have thus determined the thermal flows from matrices of instrumented forging, with identification of flows by a code of calculation by finite elements. The values of the parameter of Archard have been taken constants for the calculation of the Wear; for their simulation, the authors use numeric values that have been obtained on a tribomètre
Roller/disk to high temperatures of the University of Technology of Compine (UTC).
To identify the thermal flows and try to take into account the effects of conduction and friction, the contact zones between the land and the tool have been broken down into 3 areas (Figure.9). This allows to identify the flow for each zone.

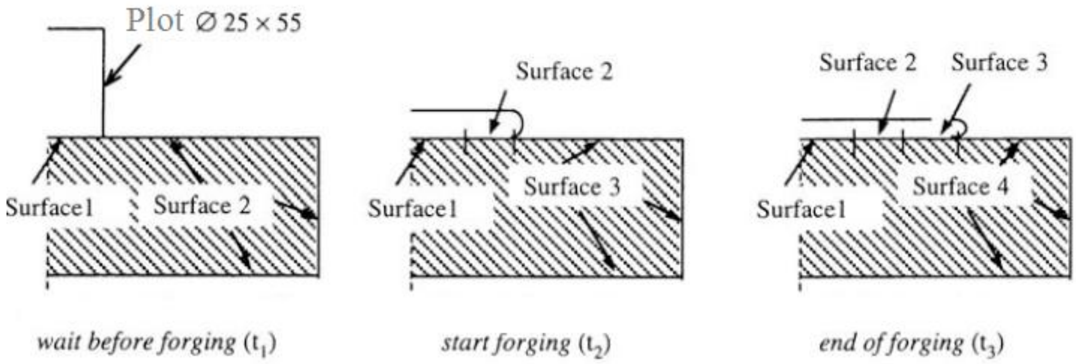

Figure.9: Location of different surfaces taken into account in the identification of thermal flux [14].

To model the damage by thermal fatigue, they have used an act of behavior of type " rounded "taking into consideration the viscoplasticity, the isotropic hardening and the kinematic écrouissages linear and non-linear, all coupled with results of fatigue oligo-isothermal cyclic carried out up to the rupture. By comparing the actual damage of wear and those simulated, they find a gap in the Losses of coasts (under estimated locally by the simulation). This gap can be explained by the mechanisms of wear not modeled (abrasion of hard particles of carbon).

The identification of the thermal flows has shown that the faïençages are associated with "flashes Important" generated by the friction and high speeds of plastic deformation.
The taking into account of the flows as well identified in the thermomechanical modeling allows determining the depths affected by plastic deformation (Figure.10). The location of these deformations allows you to predict where the damage can occur. The plastic deformation presented accumulated on the Figure.5 sum the loss of coasts by wear and the thickness of the layer residual distorted at the end of the test. In fact, the authors consider that the loss of coasts by wear, is a layer that before to be abraded, is deformed plastically.

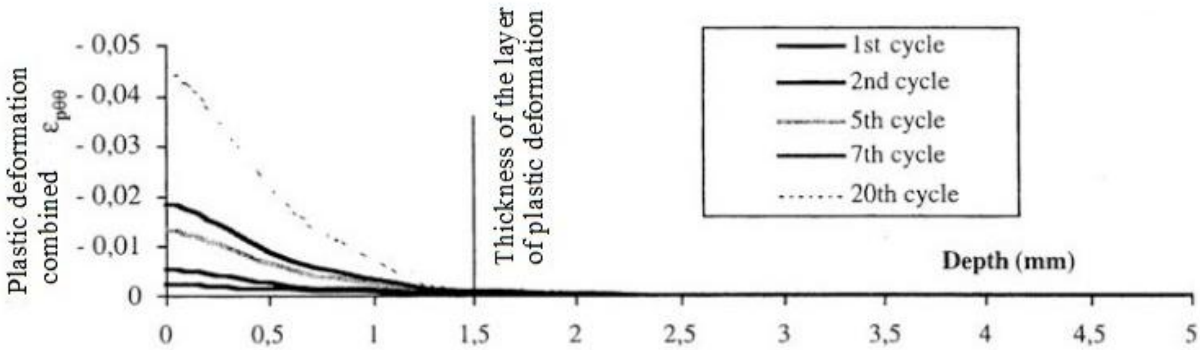

Figure.10: Accumulation of the plastic deformation in function of the number of cycles [14].

3.4.2 Model of Archard based on the softening

The literature on the forging claims that the Wear by abrasion is responsible for approximately 70% of the scrapping of the matrices, it is therefore essential for the industrial sector to have an estimate that is as accurate as possible to the wear of the matrices in conditions of forging. In his thesis, Y. Thoré [15] has developed a model based on the act of Archard [3] from results of wear obtained during crushing tests of pile dishes (equation 7). The coefficient ka, determined experimentally, summarizes all the mechanisms involved in the process of wear, and which have not been quantified (influence of the film of transfer Calamine and lubricant, evolution of microstructure,…).

$$W = K_A\, p\, d / Hv^{m} \qquad (7)$$

With W the worn Volume (m^3),
And m exponent expressing the influence of the hardness on the rate of wear ($2 \leq m \leq 3$),
P the normal force (N),
Of the length of landslide (m),
K_A the coefficient of wear of Archard,
Hv the hardness of the matrix ($300 \leq hv \leq 1200$).

4. Conclusions:

In our study, we will look at the influence of the initial hardness of the steel on the friction and wear. The wear will be in the following defined as the geometric modification of the surfaces in contact. However, the emphasis will be on the nuance to 47 HRC, widely used in hot forging. It is expected that a difference in behavior appears, in particular to temperatures close temperatures of income.
Taking into account the conduct of our test, the oxidation of Z38CDV5-3 should not be significant since the pin is left to ambient temperature before the test. The time of exposure to high temperatures are not sufficient to have layers of oxides very developed.
Recall that the field of constraints developed in the pion and in the disk is not the same. As well, the effects of fatigue, suffered by the two antagonists are different. This is reflected by the kinetics of wear of the pin and the disk.
The last part of this study highlights the complexity of the implementation of an act of wear "universal" which would take into account the whole of the modes of damage. It appears more reasonable to attempt to associate a model of wear to a type of degradation in order to limit the number of parameters and keep a law that is readily usable in the laboratory or industrial way. Nonetheless, there is generally a mechanism of predominant wear in a tribological system. This presentation shows us that it will take in the suite, attach particular importance to the identification of the parameters that control the wear in our investigation, in anticipation of the modeling of the damage to theZ38CDV5-3.

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