Research on the Influence of Alloying Elements on the Behaviour of the Cladding by Welding of Steels

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At a time of raw materials and energy crisis, when the world becomes increasingly energy-intensive and well aware of the importance of the concept of sustainable development, technological equipment repair and refurbishment processes are particularly important. Plating strong functional surfaces of parts required during operation gives it corrosion resistance properties and even better resistance to wear and corrosion. Cladding refurbishment involves playing the functionality of defective parts and means, most often confer improved properties for the use of reconditioned parts or products much better than the new. In order to choose the most appropriate couple basic and filler material, the paper presents, the influence of the main alloying elements of steels used in manufacturing the most categories of items that are subject to cladding.

Keywords: sustainable development, efurbishment processes, filler material

The cladding surface is to modify the technical properties , functional and economic considerations along with the modification of their geometric characteristics in accordance with the functional role. In most technological applications , plating involves depositing a layer or more layers of a filler material , most often with high resistance to wear and corrosion, on a support layer, made of a different material, most often one of the most inexpensive material .

The process of making this depositing layers is different, depending on the chosen plating process , but the most commonly used method is cladding by welding.

The most commonly encountered methods of cladding by welding are manual electrical arc welding with coated electrodes, welding in the environment of shielding gases, automatic submerged arc welding with electrode strip, oxyacetylene welding and special processes for welding (plasma , electron beam , photon beam , etc.) . Whatever the welding process especially for cladding had designed and made the process so that deposited layers of filler material to be done without any deviation from continuity, shape, size , appearance, structure, physical, chemical , mechanical, geometric, and without imperfections [1, 5].

Also, any of the welding processes used to achieve cladding parts or products should be well known phenomenon of dilution of both base and filler material as dilution has the following effects :

- reduction of the corrosion resistance ;
- reduction the wear resistance or hardness reduction ;
- reduction in tensile strength ;
- reduction the fatigue strength ;
- Increasing or decreasing the sensitivity to cracking.

Dilution is defined as the ratio between the penetration depth *p* and the total thickness of deposited layer h_t , as shown in figure 1 and 1.1 relation.

$$Dilution = \frac{\text{the penetration depth}}{\text{the total thickness of deposited layer}} * 100[\%] \qquad (1)$$

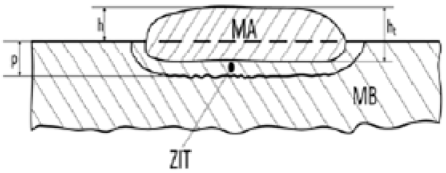

Fig. 1 Elements of the dilution

Experimental part

Research on materials that may be the subject of the reconditioning by cladding

Because it was done experimental tests regarding the cladding on several types of parts, made of different materials, it will be done a synthesis of these materials, needed for the election of the proper couple base and filler material. [2, 12].

The steels are the most common materials used in manufacturing of the most parts of the technological equipment used in metallurgy, machine building industry petroleum and petrochemical industries such [4, 8], such as:

- *carbon and low alloy steels*, are delivered in a rolled state, in a wide range of products, advantageous to be used without special technical conditions. The yield strength of these steels is 240 ... 360 N / mm^2 and the toughness is guaranteed at temperatures up to - 20 ° C. Examples: S235 JR with max. 0.20% C, max. 0.80% Mn max. 0.40% Si, is used for load-bearing elements in welded construction or joined by other methods: tanks, columns, elements, structures of machinery and equipment; OL52 with max. 0.20% C, max. 1.60% Mn, max.0,50% Si used for high capacity tanks; OLT65 with 0.40 ... 0.50% C, 0.70…1.00% Mn , 0.17 ... 0.37% Si, used for high pressure seamless pipes;

-steels with increased resistance to atmospheric corrosion are alloy steels whih contain alloying elements that increase metal resistance to the corrosive effects of weathering and are designed for the construction with high index surface / construction ton. Usually these steels are difficult to maintain;

-fine grain steel are made in controlled technological conditions, to obtain a fine structure ferrite - pearlite,

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characterized by high values of yield strength up to 460 N / mm^2 and guarantees for toughness down to - 50 ° C. Flat and profiled products delivered in rolled or normalized state, controlled are intended for execution of slender structural design; (Eg, X56 and X60 with max. 0.26% C, max. 1.35% C , min.0,005% Nb; min.0,02% V; min.0,03% Ti), applicable for welded pipe;

-steels with high yield, are delivered in heat-treated alloy steel for obtaining metallurgical structure bainite mostly, favorable execution with minimal technological precautions of performance welded constructions. (Eg C420 with max. 0.20 % C, 1.10 ... 1.60% Mn, 0.15 ... 0.40% Si, max.0,70% Ni, used for containers with very thick walls);

- stainless steel are Fe-C-Cr alloy containing at least 12% Cr, less than 0.1% C and have therefore presented in a more or less corrosion resistance in various work environments: liquid, solid or gas or hot oxidation resistance. 12% Cr content gives the steel, a property of a cover for the passive layer (adherent oxide) in the different media (air, water, acids, industrial atmosphere, etc.) making them resistant to oxidation and corrosion, compared to other metallic materials. The protective layer formation is possible only in oxidizing environments, the presence of oxygen is required to maintain the protective layer. The passive layer consists mainly of chromium oxides and is sticky, dense, waterproof and less soluble, which makes it resistant to a large number of aggressive media. In order to create parts of the chemical and petrochemical industries that are becoming more aggressive at higher temperature and pressure, they were created several grades of stainless steel, which have been obtained by adding Fe-Cr-C alloys Cr various factors, such as: nickel, molybdenum, copper, titanium, niobium, silicon, boron, aluminum, etc. [9, 11].

Chromium and nickel are the two main elements of alloy stainless steels. Adding other alloying elements improve:

- corrosion resistance in wet environments (molybdenum and copper);
- resistance to oxidation at high temperatures (silicon, aluminum, tungsten and molybdenum);
- mechanical characteristics at high and low temperatures (tungsten, molybdenum, niobium, cobalt);
- metal cutting properties (sulfur and selenium).

Nickel improves in particular the corrosion resistance in acidic environments, poor oxidative or non-oxidative and raises toughness steels. Copper additions increase the nickel influence.

Molybdenum improves the resistance to local corrosion in particular environments and chlorine.

Titanium and niobium reacts with carbon to form stable carbides, increase thermal stability and resistance to intercrystalline corrosion of steel.

Silicon and aluminum increase resistance to high temperatures and improves creep behavior of stainless steels.

Manganese is added as a substitute for nickel and its effect gamagen allow lifting economic index of stainless steels.

Range development and diversification of production of stainless steel is formed mainly of flat materials (plates, slabs) and thin (pipes, capillary tubes).

Chemical and petrochemical industry currently consumes about 70% of flat products and 50% from other products.

The alloying elements of stainless steels is aimed primarily at increasing corrosion resistance and improved mechanical and physical properties. The alloying elements alter the structure and classify stainless steels into various classes, which have specific physical and mechanical properties.

Since the experiments were done in many different configurations parts made of different materials requires a careful analysis of the influence of different alloying elements in the deposited layer on the area of heat affected zone and material support, the most important being:

The influence of chromium - structural changes

Chromium is the main alloying element of all grades of stainless steel, the minimum participation being of 12%. Due to the alfagen effect of chromium, occurs restriction and even disappearance of ã phase. Chromium, raises the temperature for the critical point A3 and lowers the temperature of the critical point A4 in case of allotropic iron transformation. For additions about 12 ... 13% Cr, the critical point A3, has a temperature of about 1273 K and for A4 get down to 1093K, suppressing the existence of iron γ. In the alloys Fe – Cr with 12 ... 13% Cr transformation $\alpha \leftrightarrow \gamma$ phase does not occur and α is stable from ambient temperature up to their melting temperature. The lowest point of the loop transformation $\alpha \leftrightarrow \gamma$, corresponds to the temperature of 1123K and concentration at about 6.5% Cr and the content of 12.4% Cr causes the disappearance of γ domain. [7, 13, 15].

Depending on the content of chromium in case of Fe - Cr alloys, occur phases :

-γ = Feγ (Cr), for concentrations below 12% Cr;
- $\alpha + \gamma$, for concentrations between 12 ... 13% Cr;
- α = Feα (Cr), for concentrations above 13% Cr; σ
- σ= FeCr, for a content of 45% Cr, phase which is stable up to a temperature of 1093K;
- $\alpha + \sigma$, for concentrations of 13 ... 45 ... 45% Cr and 65% Cr, but without specifying concentrations for biphasic areas.

Phase σ has tetragonal crystal lattice and is rough and fragile. The presence of σ phase, with α phase, causes an structural hardening and a great tendency to become brittle, particularly if Fe-Cr alloy is maintained for a long time (tens of hours) in the temperature range of 873 ... 1123K.

In Fe-C-Cr alloys, the influence of chromium is similar to that shown in alloys Fe - Cr, but with other areas of existence of phases α, γ and additionally appear chromium carbides type alloy cementitious $(FeCr)_3$ and allied carbide CrxCy. The carbon, being an gamagen alloying element, cause changes in the processing loop of the γ phase. It is noted that the γ phase expands with increasing carbon content. If the carbon content is 0.6%, the suppression of $\alpha \leftrightarrow \gamma$ transformation occurs at concentrations of 18% Cr. In the concentration range of 18 ... 27% Cr, coexist ferrite

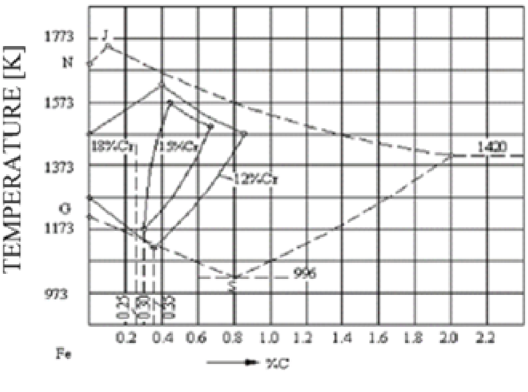

Fig .2. Influence of chromium line equilibrium diagram Fe - Fe_3C

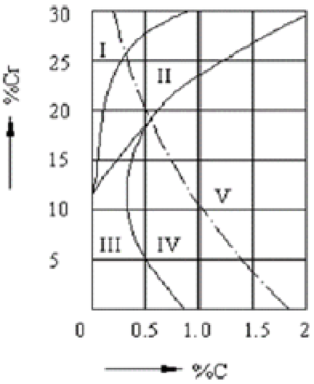

Fig. 3. Amendment steel structure according % Cr and % C: I - ferritic steels ; II - semiferitic steels ; III - hipoeutectoide steels ;IV - hipereutectoide steels ; V - ledeburitic steels

and austenite phases, and more than 27% Cr, the alloy remains ferritic, regardless of the carbon content.

Increasing carbon content above 0.6% Ti and chromium above 18%, not change the existence domain for austenite and ferrite, but increases the amount of simple or complex chromium carbides. The increase of more than 27% of chromium and more than 0.6% of carbon, leads to appearance of ferrite matrix (ferrite alloyed with chromium) and separation of Fe-C-Cr. It is formed alloy cementite $(FeCr)_3C$, containing up to 15% Cr; $(CrFe)_7C_3$ and $(CrFe)_{23}C_6$, occurring in over 15% Cr steels.

Increasing the chromium content, leads to increase the temperature for A_{cem} and A_{c3} balance lines, descent the temperature for A4 lines and reduce the carbon content of the eutectic (fig. 2). At concentrations of 12% Cr, the eutectoid carbon content will be 0.35% C instead of 0.8% C and for 18% Cr will be 0.25% C.

The structure of chrome alloy steels depends on the carbon and chromium content, and the type of heat treatment applied. Changing the structure to the content in carbon and chromium is illustrated in figure 3. Depending on the concentration of carbon and chromium, ferritic steels appear (zone I), steel with transformation of austenite on cooling (zones III, IV and V), in balance structures, appropriate to hipoeutectoide steels (zone III), hipereutectoide steels (IV) and ledeburitic steels structure (zone V), due to changes in temperature and carbon concentration in the critical points of the diagram Fe - Fe_3C. [10, 11].

In the annealed state, alloyed steels with chromium, shows: martensitic structure, that by heating at high temperatures becomes austenitic structure and can be hardened. The content in chromium of these steels is 12 ... 18%, and the content of carbon increases with increasing concentration of chromium; ferritic structure which not suffer structural changes in heating - cooling. These steels are characterized by content of 16 ... 30% Cr and increasing carbon for greater participation of chromium; martensitic-ferritic phase which suffer partial conversion to heating - cooling and is characterized by a content of 0.08 ... 0.22% C for an 18% Cr content.

Carbon and chromium content change hardening critical speed, influencing hardenability of steels. Hardening critical speed, decreases with the increase in chromium and carbon content of steel.

The hardness and certain mechanical characteristics depends on the contents of carbon and chromium, and heating temperature for the hardening and the tempering temperature.

From the experimental results obtained for steels by 12 ... 14% Cr and containing less than 0.15% C results the following: hardness levels peak (HRC 46 daN / mm^2) for a tempering temperature of 1373K and will fall below if this value if tempering temperature increases to 1473K; tensile strength Rm and yield strength $R_{p0.2}$ decrease, and elongation and resilience increased as tempering temperature up of over certain values (fig. 4). Will obtain acceptable values for these mechanical characteristics, in case of tempering at 783K or lower temperatures of 673K.

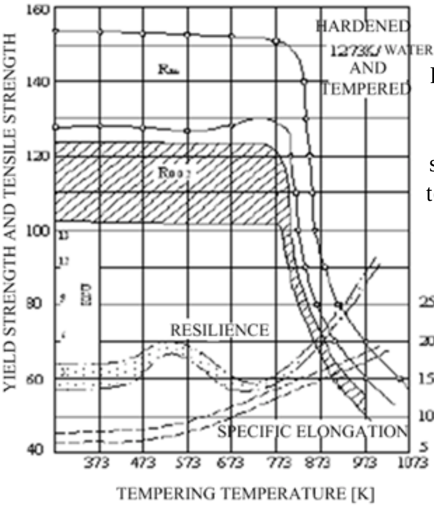

Fig .4. The mechanical properties of martensitic stainless steels according to the tempering temperature

Martensitic chromium alloy steels, shows good mechanical properties and good corrosion resistance. [5] [9]. At ambient temperature, these steels have good corrosion resistance in the nitric acid concentration of 1% boric acid; acetic acid concentrations less than 10%; picric acid; taric, uric acid, benzoic acid, etc., if they have been hardened at 1273 K / water (oil) and tempered below 673K at or above 873 K temperature. Tempering to the temperature range 673 ... 873 K promotes fine carbide precipitation, which reduces the corrosion resistance of martensitic stainless steels.

The corrosion resistance of only chromium alloy stainless steels in various media, is strongly influenced by the content of this element. There is an increase in corrosion resistance with the increasing of the chromium content (fig. 5).

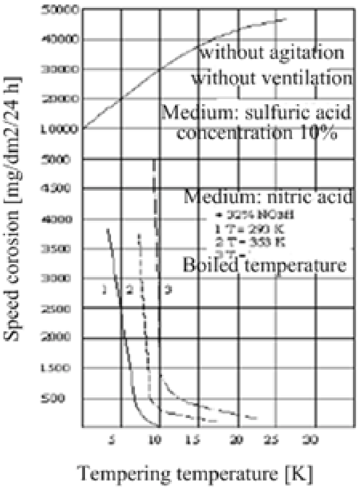

Fig. 5. The influence of chromium on the corrosion rate of the steel

The influence of nickel - structural changes

Austenitic stainless steels and ferritic - martensitic stainless steels, nickel is next chromium, principal alloying element. Participation of nickel in stainless steels should not exceed 8% for the austenitic structure (grade crom-nickel) or 4 ... 6% (grade chrome -manganese-nitrogen-nickel) and a maximum of 4% for martensitic stainless steels or martensitic-ferritic.

Nickel dissolves in Feγ and it extends the field of existence life, acting on lowering temperature for critical points of transformation [6] .

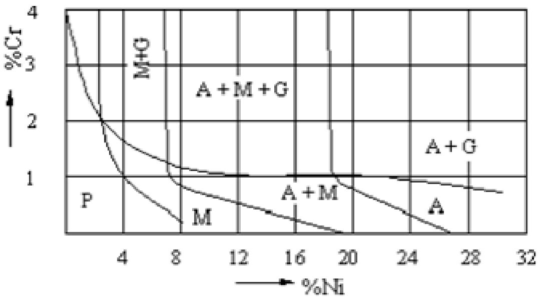

Fig. 6. Graph structural steels alloyed with nickel slow cooling: P = perlite ; M is martensite; A = austenite; G = graphite

It is noted that nickel causes an important transformation hysteresis at heating - cooling, which leads to the appearance of α + γ two-phase domain. It is noted that is influenced more strongly the temperature in cooling of critical point A_{r3}, compared to A_{c3}. At concentrations of 60 ... 80% Ni, appears $FeNi_3$ superstructure, whose presence was not observed in the nickel alloyed steels. This superstructure $FeNi_3$ dissolve in γ phase at temperatures greater than 7730 K. Due to the low speed of γ↔α transformation at temperatures below 5730 K, phase boundaries are uncertain and therefore are given by broken lines.

In the Fe-C-Ni alloys, nickel influence is similar to that shown in the alloys Fe - Ni, in addition favoring the decomposition of cementitious and appearance of graphite (fig. 6).

Taking into account the of nickel and carbon content, Fe-Ni-C alloys may present pearlite structure, pearlite graphite, graphite martensitic, austenitic and austenitic graphite. It notes the graphite occurrence in the structure if the alloy contains more than 0.8% C and 24% Ni.

At a concentration of 1.5% C, the the graphitized effect of nickel, appears to 4% Ni. In the Fe-C-Ni alloys, with concentrations up to 0.55% C appears a metastable nickel carbide Ni_3C,. The concentration of carbon for this combination Ni_3C is 6.38%. This nickel carbide was not emphasized in the structure of nickel alloy steels and as such, is considered that nickel are not form carbides and has graphitised effect.

The effect of nickel in structural changes for the stainless steels (Fe-C-Cr- Ni alloys,) is it is revealed by analyzing of some sections from ternary diagrams. Depending on the contents of chromium and nickel and for constant carbon concentrations (0.1% C) can occur in case of rapid cooling, different types of structures (fig. 7).

At constant concentrations of chromium and carbon (18% Cr and 0.1% C) steel structure changes with increasing nickel content.

One can predict with fair accuracy that the nickel causes in chromium-nickel stainless steels two important phenomena: extension of austenitic range and the increase of the stability of austenite; the establishment of the σ phase (FeCr) at high temperatures and appearance of it at lower concentrations in chrome, comparative with stainless steels chromium alloyed only [6, 7].

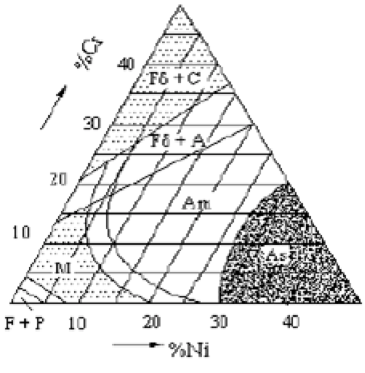

Fig .7. Cross-section of the ternary diagram to the Fe -Ni -Cr concentration of 0.1 % C Figure 7 Influence of nickel on the martensitic transformation temperature

Nickel influences the temperature of steel critical points of transformation. It obtain a descent with 10 ... 11K for A1 critical point for each percentage of nickel. For about 15% Ni, the carbon concentration of S point (eutectic point transformation) of Fe_3C diagram is 0.15% at the temperature of 893K.

Nickel acts upon lowering the critical points of martensitic transformation (fig. 8). The steel 18-8 hardened and then cooled to 77K (liquid nitrogen) will suffer a partial transformation to martensite, transformation that is not reversible and will affect mechanical properties. The temperature at which this transformation occurs, is the lower as the more the content of nickel, as a result of lowering the critical point Ms (martensitic transformation start).

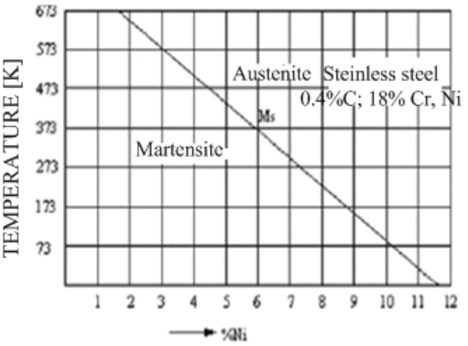

Fig .8. Influence of nickel on the martensitic transformation temperature

Nickel reduces the hardening critical speed and therefore increases the steels hardenability. With increasing in the nickel concentration, appears a stronger influence on the hardening of the steel (fig. 9). This is valid for steel construction and is supported for martensitic stainless steels. Austenitic stainless steels this influence does not appear due to the movement of critical points martensitic transformation at low temperatures.

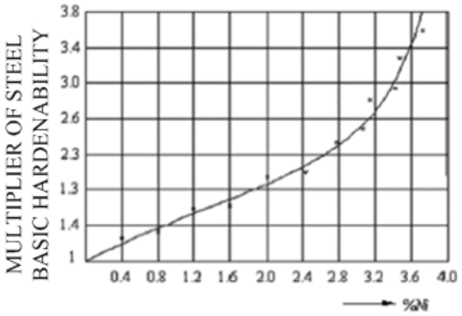

Fig .9. The influence of nickel on steel cãlibilitãþii

Tempering and hardening temperatures of martensitic stainless steels are influenced by the nickel content [1, 2].

The increase in nickel content stabilize austenite and lead it to martensite transformation. The action of hardening for the austenitic Cr-Ni steel, which has 0.08% C is shown in figure 10. The hardening factor decreases with increasing of the nickel content. Nickel will influence the mechanical properties of the steel according to his contents (fig. 11).

At chromium-nickel stainless steels, nickel influence on the mechanical properties will be similar and will contribute to increasing the toughness and plastic deformation processing. Increasing the chromium and nickel content causes the increase in tensile strength which is higher after severe plastic deformation (fig . 12), and the specific elongation decreases with increasing of the applied degree of deformation.

As found experimentally, corrosion resistance of chromium-nickel stainless steel depends mainly on the

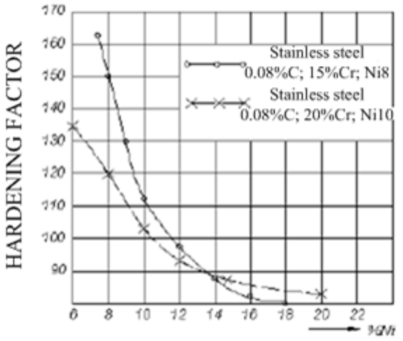

Fig . 10. The influence of nickel on hardening stainless steels

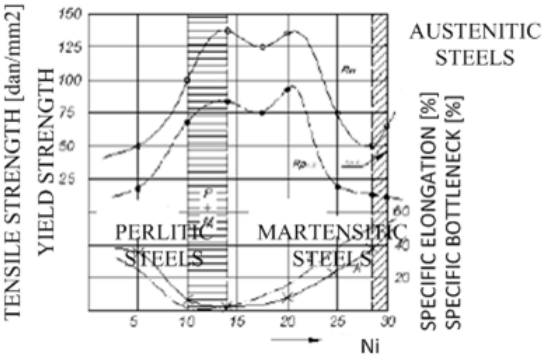

Fig . 11. Influence of nickel on mechanical properties of steels due to changes that produce them

presence of chromium carbides in the structure or if there is an austenite with a high degree of homogeneity. Separations of chromium carbides, to the austenite grain boundary, will deteriorate the corrosion resistance of chromium-nickel stainless steels. In order to obtain corrosion resistant steels, separation of chromium carbides should be avoided, either by alloying with Ti or Nb, or by modifying the ferritized elements, which give rise to a quantity of 1 ... 8% ferrite besides austenite. It is noted that the sensitized steel , which has the structure chromium carbides precipitated at the grain boundary, has a lower corrosion resistance, and the stabilized steel with Ti or Nb, which has the austenitic-ferritic structure, will be resistant to corrosion;

·the influence of other alloying elements (Mn, N, Mo, with, Ti, Nb, Co, B, S, Se, P).

Cr-Ni steels is expensive due to the high cost of nickel, so in order to reduce the price

$$ENi = Ni + 30C + 0,5Mn + 30N \quad (2)$$

$$ECr = Cr + Mo + 1.5Si + 0.5Nb \quad (3)$$

In these relations, instead of the symbol we write the percentage of alloying elements.

The range of brands is wide and a rational choice can be done only given a set of criteria, namely:

- resistance to corrosion;
- mechanical strength characteristics;
- particularities of constructive conception and realization of the construction proces
- economic efficiency.

The share of each of before criteria, determine the choice of brand steel is dependent on the user.

Conclusions

Cladding of the parts may constitute a production process by itself or mixed, executed, with other manufacturing and repair processes etc, especially in the petroleum and petrochemical industries.

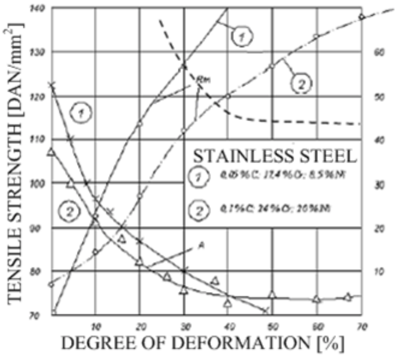

Fig . 12. Variation of the mechanical characteristics of stainless steel, depending on the chromium and nickel content and the degree of deformation

The training of new (base material – filler material) is individual for each material, so, each case must be studied using the latest achievements in this field.

Literature usually recommended several filler materials for different operating conditions and for certain basic materials. It is insufficient the knowledge of the processes occurring in the contact layers of halves claded tribological coupling and the influence of these processes on the reliability of singular components and entirely systems.

Because they have developed many cladding processes, new materials for cladding appeared and even more new technologies.

Always material deposited by cladding surface, will have better mechanical characteristics than those of the piece and in endurance, a cladded piece withstands at least 2 ... 3 times more.

Depending on the importance of the plate and the cladding costs may choose different cladding methods;

Choice of method and cladding technology must be closely aligned with the type of surface and the load application of the piece during operation.

The choice of materials couple in the base and deposited layer is the most important stage of any process of cladding technology, with direct influence on all other stages of the process.

Chemical, oil and petrochemical rail transport and metallurgical industry, uses increasingly aggressive environments, temperatures and pressures increasingly higher, which led to the creation of numerous qualities of materials used for layers deposited by welding cladding.

Limits of using the cladding technologies are given by: technical factors (resistance to wear and corrosion, durability, strength, functionality, interchangeability etc.); technological factors (productivity, cost, nature of production, process availability, etc.); economic factors (costs of new parts and refurbishing the track, the durability of new and reconditioned piece, the batch size, etc.) and organizational factors (specificity of activity of the company, management strategy, the frequency of interventions etc.).

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Manuscript received: 10.08.2015