A combined surface layer strengthening of aluminum alloys by plastic deformation and vacuum ion plasma processing methods

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Abstract. The influence of tool effects of the processing media on formation of corrosion characteristics (reactive capacity and corrosion resistance) in the surface layer of aluminum alloys during strengthening by surface plastic deformation and vacuum ion-plasma processing has been investigated. It has been shown, by example of V95pchT2 alloy, that formation of the surface layer corrosion characteristics under the integrated effect of processing media (shot, plasma) is determined by the interaction modes of the tool/work surface contact pair. The influence of reactive capacity, which has been formed during strengthening, on changing corrosion resistance of the strengthened surface layer under the action of 5 % solution of NaCl (120 hours test base) has been considered.

1. Introduction
Formation of the surface layer reactive capacity during generation of modified surface structures using surface plastic deformation and vacuum ion-plasma processing is the prime task implemented in surface strengthening processes. The given parameter of the surface layer characterizing its readiness to interact with the environment is responsible for origination of new internal (subsurface) and external (supersurface) structural compositions, which provide development of the required service properties. Reactive capacity of the surface layer is determined by its structural condition formed by preceding process effects as well as the presence of different types of barrier layers on it that appear under these effects or when they are finished. The study of dependence of the surface reactive capacity on operating modes with surface strengthening processes is very important both for the use of this knowledge at justification of processing modes and for development of additional protective barrier layers during surface forming with the aim to protect them against in-service effects of corrosive outdoor environment.

2. The change in energy characteristics of the surface layer under tool effects of the surface plastic deformation and vacuum ion-plasma processing
The complex physicochemical processes occurring at the surface of the processed part under tool effects as well as effects of high-energy flows of gas and metal plasma and other types of process effects generate the structural condition and appropriate surface energy state. The quantitative and qualitative characteristics of the surface energy state are represented by a reduced surface potential $V_p$.
That surface layer parameter is a structural-dependent value as well as reactive capacity reactive capacity of the surface layer; therefore according to the variation of $V_p$ values we can also judge changes in reactive capacity.

During the progress of surface strengthening the process effects primarily influence the change in physicochemical, mechanical and energy properties of the surface layer of metal materials being processed including those of aluminum alloys. Investigation of the interaction of the surface energy state with its reactive capacity at different stages of surface strengthening is highly topical for performance evaluation of the processing media effects in treatment, and also for quality assessment of created surface structures.

Investigations conducted have shown that the interaction of the surface energy state with its reactive capacity is traced from the initial stage of the process tool effect performed during part manufacture. As a rule, a blank of the future part has no design surfaces and possesses initial surface structure inherent in the “inner” structure of the basic material. When the processing tool influences the blank, the structurally changed “defective” surface with a very high reactive capacity is formed. The time of existence of the surface in such a state is extremely small and measurements of the energy state and reactive capacity are not practical. The subsequent exposure of highly activated surface to the process atmosphere gives rise to formation of “contaminated” multicomponent surface layer consisting of various adsorbents, simple and composite oxides. The change in the energy properties of the surface layer takes place over the whole processing time (especially active at the beginning); and with processing completed, we can measure the value of the energy state of the surface and evaluate its reactive capacity. The in-process cleaning of the surface after processing leads to change of the energy state of the surface, and measuring of the reduced surface potential $V_p$ makes it possible to draw the conclusion that its reactive capacity changes. In storage the surface of the finished part is under the action of time and atmospheric factors with the resulting formation of the final structure of the part surface layer. The $V_p$ value can be measured when parts are in storage and in doing so to keep track of stability of the finished part surface, figure 1 (modes 1 and 2).

The values of $V_p$ are determined by material grade. It is shown by the example of V95pchT2 alloy that aluminum based alloys the values of $V_p$ are, as a rule, in the negative region through formation of considerable oxide layer at the surface. Being non-mechanically stable and under the effect of tangential stresses arising during machining, surface oxide is easily removed as design surfaces of the part are being developed.

Recovery of the removed surface oxide at the newly formed surface occurs almost instantly because there remains its high reactive capacity. The value of $V_p$, which characterizes the presence of the oxide, is hardly changed, figure 1 (mode 2) despite the fact that defect structure of the surface layer has changed under machining (milling). The change in the defect structure of the surface layer generated under machining has more intensively influenced the change in resistance of the surface layer to the action of corrosive medium (5 % solution of NaCl). The conducted investigations have demonstrated that existence of the defective surface layer brought about an increase in intensity of the corrosive medium action and formation of a large amount of corrosion product, figure 2 (mode 2), which was favourable to reduction in mass of the test specimens (salt-spray cabinet, test base 120 hours).

Technological effects of the processing media during surface plastic deformation affect to a great extent the variation of the surface energy state since deformation and contact processes, while being their basis and facilitating the change of structural condition of the surface layer, change its surface chemical composition of elements and the surface energy state.

At the initial stage of treatment, when realizing surface plastic deformation methods we observe shattering of metal (alloy) grains into blocks (subgrains) and production of mosaic structure with subsequent formation of the texturized structure with anisotropic mechanical properties. As a rule, for every structural condition there is a definite value of surface energy state. Therefore every stage of the technological effect during surface plastic deformation has its value of the surface energy state that determines its reactive capacity.
Figure 1. Change in values of $V_p$ of the surface layer of V95pchT2 aluminum alloy against surface condition: 1 - pure Al-99.9%; 2 - milling; 3 - milling + peen forming (30 s); 4 - milling + peen forming (120 s); 5 - milling + ion etching $U_{ref} = 0$V; 6 - milling + ion etching $U_{ref} = -100$V; 7 - milling + plasma flow Ar-N-Al (20 min); 8 - milling + plasma flow Ar-N-Al (60 min); 9 - milling + plasma flow Ar-N-Al (40 min); 10 - milling + vibro strengthening with chips (Si) 60 s; 11 - milling + abrasive vibro strengthening + plasma Ar-N-Al (20 min); 12 - milling + abrasive vibro strengthening + plasma Ar-N-Al (40 min); 13 - milling + abrasive vibro strengthening + plasma Ar-N-Al (60 min).

Figure 2. Mass variation of test specimens under the action of corrosive medium (120 hours, salt-spray cabinet – 5% NaCl) of the surface layer of V95pchT2 aluminum alloy formed by different processing modes: 1 - pure Al-99.9%; 2 - milling; 3 - milling + peen forming (30 s); 4 - milling + peen forming (120 s); 5 - milling + ion etching $U_{ref} = 0$V; 6 - milling + ion etching $U_{ref} = -100$V; 7 - milling + plasma flow Ar-N-Al (20 min); 8 - milling + plasma flow Ar-N-Al (60 min); 9 - milling + plasma flow Ar-N-Al (40 min); 10 - milling + abrasive vibro strengthening; 11 - milling + abrasive vibro strengthening + plasma Ar-N-Al (20 min); 12 - milling + abrasive vibro strengthening + plasma Ar-N-Al (40 min); 13 - milling + abrasive vibro strengthening + plasma Ar-N-Al (60 min).

The intensity of variation in surface energy state values depends on the energy and time of work tool action on the surface layer under processing, its geometric parameters and scheme of its contact with
the surface as well as material of the tool/work surface contact pair. The use of shot peening with steel spheres made for significant change in Vp values and provided its transfer from the negative region of values to the positive region, figure 1 (modes 3 and 4). Such changes of Vp values are associated with appearance of contact deposited Fe on the work surface layer of aluminum alloys and forming on its base of a complex alloyed oxide with low reactive capacity. Reactive capacity of such oxide is structurally stable and Vp values do not change during a long period of time (test base is more than 2 years). Variation in time of the work tool action on the processed surface from 30s to 120s actually had no effect on the generated Vp values, but it significantly influenced the amount of contact deposited Fe resulting in decrease of the processed surface resistance to corrosive medium, figure 2 (modes 3 and 4).

Application of the surface vacuum ion-plasma processing based on the effect of high-energy gas and metal plasma flows expands the range of variation of surface layer properties. Thus the action of Ar gas plasma flow during ion etching of the milled surface with reference voltage $U_{ref}$=0V retains initial value of Vp and its reactive capacity, here we observe corrosion resistance of the formed surface, figures 1, 2 (mode 5). The increase in the reference voltage has raised Vp value to -100V through impact action of Ar accelerated flow on the surface, in this case corrosion resistance remains at the previous level, figures 1, 2 (mode 6).

Exposure of the milled surface to gas–metal plasma flow (Ar-N-Al) considerably influenced the change in Vp values and corrosion resistance of the surface being formed, figures 1, 2 (modes 7, 8, 9). Processing with plasma flow within 20 minutes has facilitated the transition of Vp values to the positive region and significant growth in corrosion resistance of the processed surface (mode 7). The increase in processing time to 60 minutes has led to recovery of the negative value of Vp and decreasing of corrosion resistance (mode 8). Reduction in processing time to 40 minutes favoured the recovery of surface layer parameters up to values obtained at 20 minutes mode of processing (mode 9).

The mode of vibro strengthening the milled surface with ceramic chips to a less extent affected the variation in Vp values and corrosion resistance than peen forming, figure 1, 2 (mode 10). Additional treatment of the generated surface structure (mode 10) with gas – metal plasma flow (Ar-N-Al) has caused the transition of Vp value to the positive region of values and growth of corrosion resistance of the surface under formation, figure 1, 2 (modes 11, 12, 13). As a result, increasing time of exposure to the gas – metal plasma flow adversely affects the corrosion behavior of the formed surface layer.

3. Conclusions

Consequently, process effects on the contact pair tool/work surface during surface plastic deformation lead to interaction between contact surface layers, which results in changes of the structural and phase states of the surface layer, variations in its surface microhardness, roughness, and energy state as well as its chemical composition that ultimately provides development of residual stresses, reactive capacity, which, in turn, determine serviceability of the processed surface. The generated structures and implementable variety of properties determine objectively controlled characteristics of the surface layer including control of the changes in the chemical composition of the surface layer, its roughness, energy state, surface microhardness, residual stress levels, corrosion resistance, which evaluates the subsequent operating capacity of created surfaces.

Post processes of the interaction of argon and nitrogen plasma flows as well as aluminum plasma flow with the processed surface of V95pchT2 aluminum alloy at the stages of vacuum ion-plasma processing are associated with the change in chemical composition of the processed surface during removal of adsorbed elements and oxides. The realizable interaction of the cleaned surface with elements of gas and metal plasma at modification stage and deposition of coatings based on the oxynitride aluminum composition changes the relation of alloying elements in the surface layer, which promotes plasma chemical reaction behavior. V95pchT2 alloy belongs to Al-Zn-Mg-Cu system and oxide film at the surface is formed involving all elements found on the surface. Processing with argon-
nitrogen-aluminum gas metal plasma provides nitrogen enrichment in the surface layer and change in its structure depending on the value of reference voltage.

References
[1] Sulima A I, Shulov V A and Yagodkin Yu D 1988 Surface Layer and Operational Properties of Machine Parts 240
[2] Petrov L M and Plikhunov V V 2012 Aviation Industry 1 22–6
[3] Iliyin A A, Plikhunov V V and Petrov L M 2011 Aviation Industry 2 28–32