Mechatronic Systems 2

Applications in Material Handling Processes and Robotics

Edited by

Leonid Polishchuk
Orken Mamyrbayev
Konrad Gromaszek

ROUTLEDGE

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Chapter 11

Synergetic aspects of growth in machining of metal materials

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11.1 INTRODUCTION

The term "growth" means the formation on a surface of one solid of another substance when they are in contact (Kuznetsov 1956). Concerning the machining of metal materials by pressure, cutting, etc., this can be the formation of the processed material on the working surface of the punch or cutting wedge. The growth is in the state of complete compression and firmly held on this surface of the instrument.

The first experimental research of the growth formation was performed by the physicist Usachov (1952). An optical microscope, artificial thermocouples, a method of stopping the processing, and metallography were used in his research. In 1952, Y.G. Usachov found that the growth is formed from the processed material and serves as an additional cutting wedge. Later research (Kuznetsov 1956) was intended to show that the body of the growth is formed with the involvement of additional environmental factors. As a result, the growth must have a different chemical composition than the material being processed. However, our research (Posvyatenko 1996) showed the falsity of such a physical nature of the growth. Thus, at the current level of experimental technology, the basic provisions of Y.G. Usachov were improved.

The aim of the research was to determine the cause of the growth formation, the positive and negative role of this formation in the machining of metal materials as well as the practical use of the growth formation.

The theoretical part of the research is based on the principles of synergetics (Hacken 1980; Ivanova 1986; Prigogine 1986). A new area of science that studies the patterns of self-organization of ordered structures of diverse origin, focusing on irreversible processes in thermodynamically unbalanced systems, was dubbed "synergetics" (Ivanova 1994; Kanarchuk 2002).

This term coined by Hermann Haken means a concerted, joint action. The principles of synergetics can be successfully applied in the study of technological systems,

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particularly, in determining of the interaction of its components, and therefore, when solving the problem of the formation of the work determined in this paper.

This derives from the methodology of synergetics, as unbalanced thermodynamics studies, irreversible processes that lead to a decrease in entropy through the self-organization of ordered or dissipative structures, which occurs in open systems that exchange energy and matter with the surrounding medium.

For nonequilibrium systems, the main characteristic is bifurcations, the mechanism of which was investigated by I. Prigogine. According to his conclusions, the system near the bifurcation points selects one or more options for further development by random fluctuations, losing stability. The alternation of stability and instability is a general phenomenon in the evolution of any open system, which, after passing the bifurcation, can no longer return to its original state.

In the process of our previous studies (Polishchuk 2016b; Posvyatenko 2017), it has been established that from the positions of synergetics in technological systems (TS), the detail is dominant (Figure 11.1).

Due to its shape, size, surface properties, and material, it affects the kinematics and cutting physics, which includes process modes. At the same time, the interaction of the “detail-process” can be considered already stabilized. The chain of some feedback, that is, the self-organization of the TS, is the influence of the physics of the process on the physical–mechanical and geometric properties of the surface of the part. The second most important component of the TS is the cutting tool (CT). Its direct connection with the detail influences the shape and size of the latter based on the type of instrument and structural material (KM) on the instrumental (MI).

The last link is also retroactive and very powerful, since today material science is developing intensively. The geometric parameters of CT and MI influence the physics of the cutting process through contact phenomena, and the effect is reversed due to wear and stability of the CT (Polishchuk 2016a).

The tool acts very strongly on the machine through the MI and the physics of the cutting process, as can be seen from the following examples. The application of tools from high-speed steel at the beginning of the twentieth century increased the speed of cutting by 3–5 times, which could not but affect the design of the machine and the cutting process. So, only 3 years after the invention of a high-speed steel, Nicholson (USA), using a specially created three-component dynamometer caliper, investigated the components of the cutting forces of a tool from the new MI in order to enhance the design of the lathe. Thus, thanks to the high-speed steel, the machines became more high-speed, rigid, and massive (Kozlov 2019; Polishchuk 2019).

Thus, the ranking of the components of the technological system for the processing of materials by cutting in the context of strong direct impact should be considered as follows: the part–tool–process–machine. At the same time, in the interaction of individual components of the parts of the TS, there is traceable and slightly weaker feedback. For the effective development of the TS, it should be synthesized and investigated only in the interconnection of the components (Ogorodnikov 2018, 2019).

It should be noted that the buildup, as the main component of the structural material of the part, deserves special attention, since it is an important characteristic of this material at low and medium cutting speeds (broaching, screw cutting and gear cutting, drilling, planing, slotting, etc.).

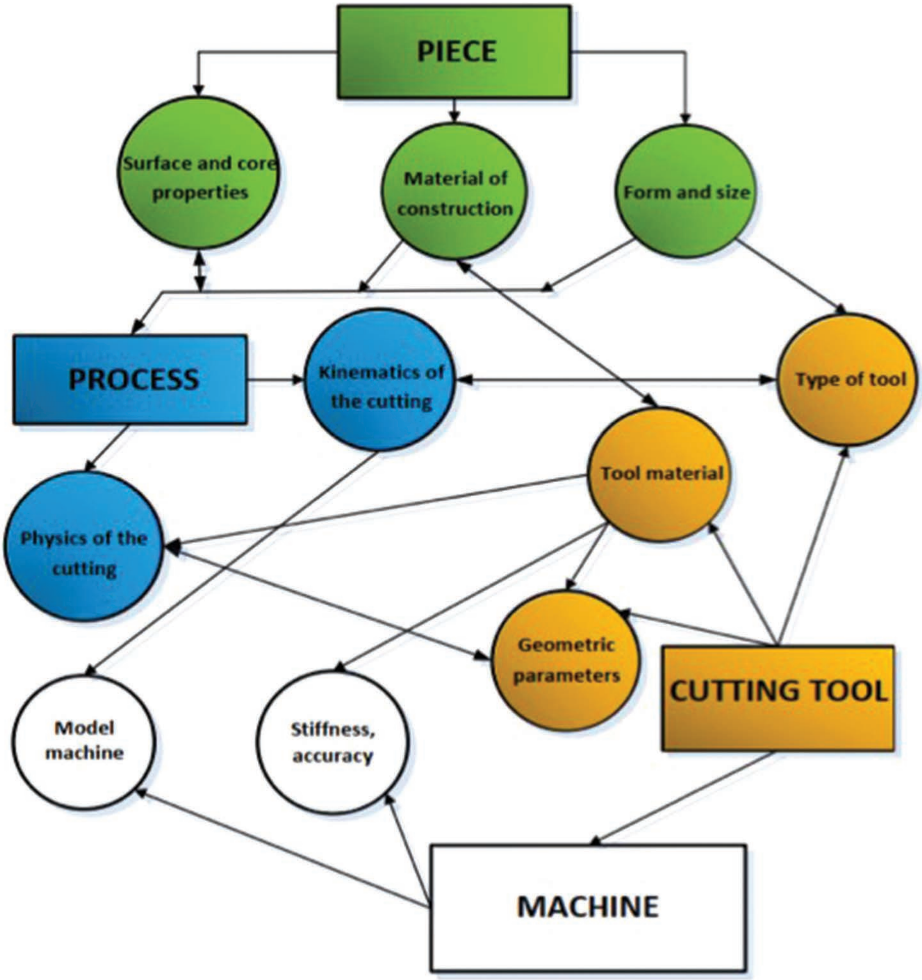

Figure 11.1 Scheme of mutual influence of the components of the technological system in the processing of material cutting.

Our previous studies (Posvyatenko 2018) also showed that the self-organization of the structure of the formation of growth during the mechanical treatment of metal deformable materials can be effectively influenced by the pre-cold plastic deformation and the medium (Dragobetskii 2015; Ogorodnikov 2004).

11.2 RESEARCH RESULTS

The following were used in the work: micro-volume PMT-3; MIM-7 and Neophot-21 microscopes; block profile-profilometer VEI – "Caliber"; REM-1064 electronic microscope and "Camscan 4-DV" scanning electron microscope; Dataletty 150 microdurometer

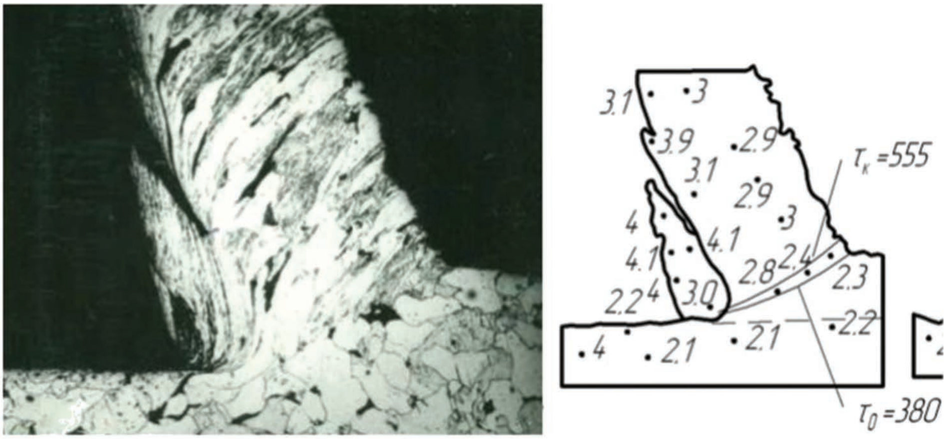

Figure 11.2 Results of the research by methods of microstructural analysis (×50) and microhardness of the chip formation zone during free orthogonal cutting of steel 10 after cold strain hardening (e = 0.25; HV 2.1 GPa): v = 0.15 m/s, Sz = 0.15 mm; cutter – steel P6M5; γ = 15°; ρ = 0.008 mm; coolant liquid – sulfoprezol; dimensional characteristics of the taut-distorted: $H\mu$ – GPa; $\tau 0$, τk-MPa.

(Shimadzu); Talisuri-5 profilograph-profilometer; Taliscan high-speed device for three-dimensional scanning of machined surface. An EWEL web camera and a latest-generation PC were also used in the experiments.

The results of the research are presented in Figure 11.2. Cutting modes: velocity $v = 0.15$ m/s; depth $S = 0.15$ mm; front angle $\gamma = 15°$; the radius of rounding of the cutting edge $\rho = 0.008$ mm; coolant liquid – sulfoprezol; microhardness throughout the cutting area – Hm, GPa; tangential stresses – $\tau 0$, τk, MPa.

The formation of the body of the growth occurs at the initial cutting area from a certain volume of the processed material, which passes into the plastic state via the deformation of the shear and compression. Practically, the formation ends after the complete inclusion of the tooth in the work. A wedged chip formation zone forms at the initial cutting area. In this case, the taut-distorted condition of the processed material near the cutting edge is such that the material, turning into a growth, acquires deformation of the relative shear $e = 20$–50 regardless of the degree of strengthening. The indicated deformation values are higher for the initial displacement deformations ($e = 1.5$–5). The microhardness of the growth significantly exceeds the microhardness of the chips and does not depend on the degree of hardening of the material being processed. So, when cutting steel 10, this reaches 30%–35% (Del 1975; Vorobyov 2017).

In the area of stable cutting, the body of the growth is elastic. By contrast, in the contact layer of the chips and the surface layer of the parts that adjoin the growth, extensive plastic deformations occur. This is proved by the texture and the increase in microhardness. Thus, in the zone of secondary deformation, the value of microhardness of the chips is close to the value of the microhardness of the growth.

The processed material turns into a growth under the action of extensive plastic deformations, but retains its structure. Thus, the growth has the same structure and chemical composition as the processed material in its original state. Exclusive to

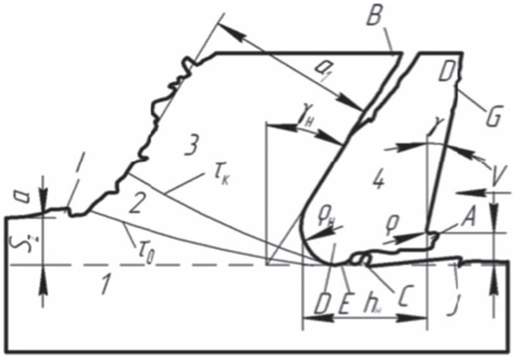

Figure 11.3 General outline of a chip-formation zone on a body of a growth: 1 – processed steel in the unstable state; 2 – chip-formation zone; 3 – chips; 4 – body of the growth.

ordinary steels, the physico-mechanical and cutting properties of the growth have an exclusively deformational nature (Kukharchuk 2017a; Vedmitskyi 2017).

In Figure 11.3, we have provided a general outline of a chip-formation zone on a body of a growth. In the chip-formation zone 2, the processed steel transfers from the elastic into the elastoplastic state.

The zone is constrained by curvilinear areas with the initial circumferential stress $\tau 0$ and the final one τk. The body of the growth 4 is found working in conditions of all-round compression. From one side, the body is restricted by the leading surface of the cutting wedge. From the other side, there is a sliding movement of the chips on the body of the growth 3. And finally, the flank surface of the growth is in contact with the processed surface. Characteristic parameters of the body of the growth and the chips are as follows. (1) part of a growth protruding over the back of the instrument; (2) cutter layer of the chips in contact with the body of the growth; (3) part of the growth remaining on the processed surface; (4) microstructure of the body of the growth at its cutting edge; (5) microstructure of the transition zone from "growth to processed surface"; (6) microstructure of the body of the growth at the cut area; (7) characteristic increase of OP after processing the growth formation (Kukharchuk 2017b; Wojcik 2010).

In Figure 11.4, we have provided a micrograph of the flank surface of the growth 1 and the processed surface 2 with a part of the growth 3 still remaining on the latter. The thickness of the textured layer on the processed surface is tenths of a millimeter in size.

Abrasive protrusions, occasionally left by the growth, break almost in half, and their underside becomes the tip of the ridge on the processed surface with hardness that matches the intense hardness of the growth. At the same time, the top part, which is also quite solid, becomes free and performs its abrasive functions on the processed surface.

In Figure 11.5, the zones of contact of the base of the body of the upright 1 with the chips 2 and the treated surface 3 are shown.

The levels of the texture of the chip 2 and the upright 1 indicate different degrees of cold strain and, accordingly, strengthening.

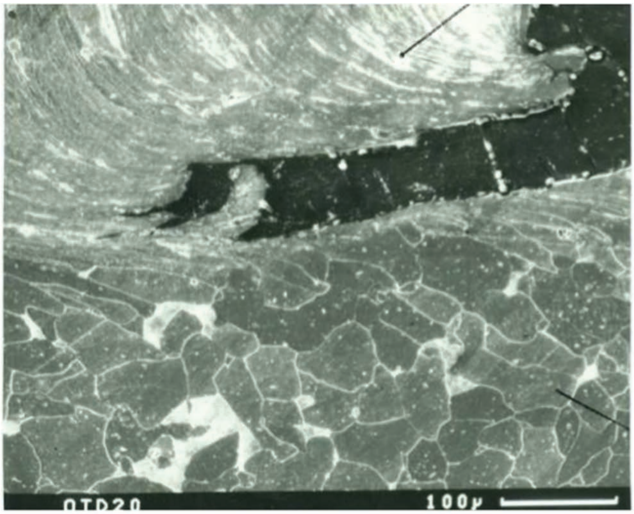

Figure 11.4 Micrograph of the back surface of the topside 1 and the treated surface 2 with the remaining particle on the last (region C in Figure 11.3). Experimental conditions are given in the caption of Figure 11.2.

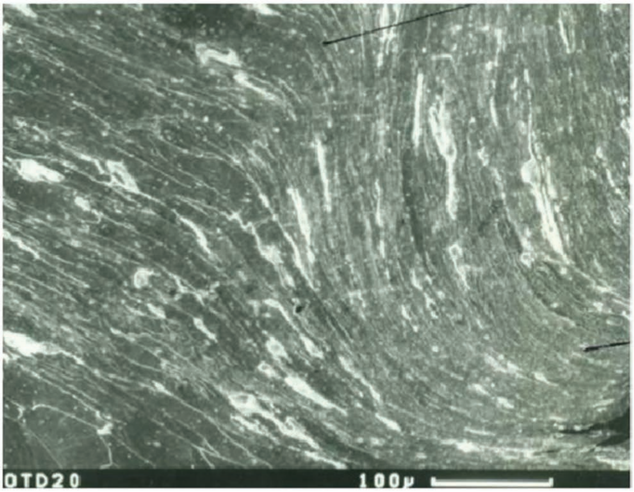

Figure 11.5 Microstructure of the contact zone of the base of the upright 1 and chips 2. The conditions of the experiment are presented in the caption of Figure 11.2.

11.3 DISCUSSION AND PRACTICAL SIGNIFICANCE OF THE RESEARCH RESULTS

The positive role of the growth is to protect the working surface of the tool against wear and hardening of the treated surface. The negative properties of the growth include the growth of roughness of this surface due to the appearance of scallops (Posvyatenko

2019b, 2019c). Growth formation can be used to construct the flow curves of plastic materials. This is due to the fact that in one experiment, it is possible to obtain a wide range of hardnesses of the processed material from the initial to the maximum (hardness of the growth; Posvyatenko 2005; Wojcik 1997).

Such curves are constructed as follows. First, we carry out the processing of plastic material by way of free orthogonal cutting in the zone of the intense formation of growths. Then the process is stopped by the cutter method, which falls, that is, the "root of the chip" is obtained.

The latter is processed by the method of preparation of microsections. Then the microhardness of an experimental sample of the "root of the chip" is studied in the zones: that corresponds to the initial state of the material; in the beginning and at the end of the wedge-shaped section of the chip formation; in an array of chips; at the contact point of a chip with a cutting tool; and finally, in the body of the growth.

These microhardness values (according to Vickers) are known to be related to the values of normal or tangential stresses by simple dependences, by which one can construct an exact yield locus, and to the strain strength of the material.

In the latest studies using the method of studying the distribution of dislocations using an electron microscope, the decisive influence of the dislocation mechanism on the change in the properties of the material being processed under cold plastic deformation is shown (Posviatenko 2019a).

11.4 CONCLUSION

It was established that the mechanical treatment of steels is accompanied by the formation of a "material – tool" in accordance with the laws of the self-organization of the system (synergetic). The growth has the same structure and chemical composition as the treated material. Exclusive for conventional structural and low-carbon steels, the physical–mechanical and cutting properties of the growth have an exclusively deformation nature.

When selecting materials for parts of machines that should work in conditions of long cyclic loads, one should prefer those materials in which the difference between the values of the tensile strength and yield strength is not less than 40%–50%, that is, plastic materials.

The article proposed an original method for constructing a yield locus and determining the limit of cold strain hardening of plastic materials, which includes obtaining a "root of the chip," investigating the microhardness of the latter inclusive and the zone of growth, and recalculating the microhardness into normal and tangential stresses.

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