DOI:10.34918/87429

Jacek PAWLICKI[1], Adam PŁACHTA[2]

9. NEW TECHNIQUES FOR THE PRODUCTION OF MATERIALS AND STRUCTURAL ELEMENTS IN THE CONSTRUCTION OF MODERN MEANS OF TRANSPORT

9.1. Introduction

In the development of any new technology, it is important to determine the moment at which the results of research carried out at laboratory and technological sites can provide a sufficient basis for developing assumptions and formulating unambiguous guidelines for launching a new technology under industrial conditions. It is therefore justified to determine the level of technological readiness, which will clearly and transparently determine the level of technological advancement, thus causing the interest of potential recipients.

The construction of modern means of transport depends on the possibility of using new materials and processing technologies. The new challenges facing the development of the mobility of the future are already well defined. It is mainly the use of light metal alloys and body steels of the new generation[3]. The primary purpose of using these materials is to reduce the weight of vehicles and aircraft, and thus energy consumption and increase range. Aluminum and magnesium alloys have long been the basic materials in the construction of aircraft structures. These are both casting alloys and alloys for plastic processing. We observe a growing trend of using these metal alloys also in the construction of vehicles. The development of electromobility has prompted car manufacturers to take measures to increase the share of these materials in the total

---

[1] Faculty of Transport and Aviation Engineering, Silesian University of Technology.

[2] Faculty of Materials Engineering, Silesian University of Technology.

[3] Sameer Kumar D., Tara Sasanka C., Ravindra K., Suman K.N.S.: Magnesium and its alloys in automotive applications – a review. American Journal of Materials Science and Technology, Vol. 4, No. 1, 2015, p. 12–30; Kuziak R., Kawalla R., Waengler S.: Advanced high strength steels for automotive industry. Archives of Civil and Mechanical Engineering, Vol. 8, No. 2, 2008, p. 103–117.

weight of the vehicle. In the construction of electric vehicles, we observe an increase in the use of materials with good electrical conductivity, primarily copper alloys. Copper alloys with an ultra-fine-grained and nanometric structure are an opportunity to obtain high strength and service life while maintaining good electrical conductivity.

In the aerospace industry, materials are used to work in high temperatures and aggressive corrosive environments of exhaust gases. Components made of these materials are subjected to significant, complex loads under cyclically variable temperature conditions. Extremely difficult operating conditions are also found in many vehicle power units. In turbochargers, high turbine rotational speeds are obtained in a corrosive environment of hot exhaust gases.

It is not sufficient to use titanium alloys in the construction of vehicles, in which high strength properties, resistance to various corrosive environments and high temperatures combined with low weight would constitute a competitive construction material. Already in the near future we will face the challenge of applying new technologies and advanced materials in the development of hydrogen technology and the widespread use of hydrogen in vehicle drives.

The use of new manufacturing techniques and advanced materials in the construction of means of transport requires in many cases a different, unconventional approach to the construction of technological equipment, the shape and kinetics of tool movement and the way of affecting the material during the manufacturing process. The aim of the chapter is to presents new technological possibilities of manufacturing materials and products, the use of which in the construction of modern means of transport, mobility of the future, may be an interesting alternative to conventional manufacturing techniques. The described devices are original construction studies, having no analogues in the commonly known constructions of machines and devices for plastic processing. Assessment of the current state of knowledge regarding the development of new methods of plastic processing intended for the processing of advanced materials and the production of products with complex geometry in one operation allows us to conclude that these methods significantly expand the range of possibilities of influencing the structure and properties of products. An important factor that determines the application possibilities of new methods of plastic formation is a significant level of technological readiness of TRL (Technology Readiness Level) methods.

9.2. Segmental shaping of ribbed and shell forgings of integral elements

The segmental shaping process is a plastic processing technology aimed at application in the automotive industry for the production of axisymmetric forgings with recesses, ribbed forgings such as shield, disc, ring and in the aerospace industry for the production of coatings and integral elements, which constitute an important group of products used in the construction of aircraft and helicopter plating. The production of products with such a complex geometry and shape is always a serious challenge for designers and technologists. Conventional technological processes of plastic processing, pressing and forging require significant shaping pressures and non-standard sizes of press working spaces. Too low shaping pressures are insufficient to effectively fill the die of the ribbed forging die, and integral elements due to their large surface area are produced in the processes of cavity machining from solid charge.

The essence of the new method of plastic shaping is the possibility of obtaining recesses of large area and depth as a result of summing the recesses of individual segments with a very small pressure area and a small single recess. This process allows the production of elements with a small thickness in relation to the transverse dimension of the forging and the execution of arbitrarily spaced, local recesses (ribs).

9.2.1. The concept of the segmentation process

The concept of the segmental shaping process provides for the transition from the designed solution to the shaping of ribbed axosymmetric forgings (a), through the shaping of longitudinal shell integral elements in the reciprocating movement of work rollers (b) and in the solution, in which the working rollers acting on the shaping segments perform a sliding, circumferential, one-way movement (c) (Fig. 9.1).

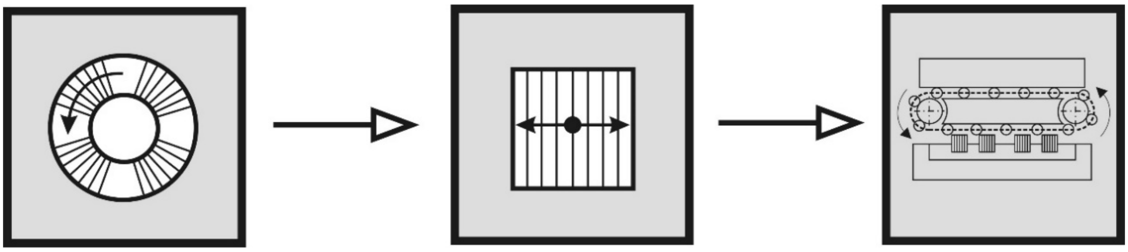

Fig. 9.1. A concept evolution of segmental forming of integral components and coverings
Rys. 9.1. Ewolucja koncepcji procesu kształtowania segmentowego elementów i pokryć integralnych
Source: Pawlicki J.: Niekonwencjonalne metody kształtowania plastycznego metali. Wydawnictwo Politechniki Śląskiej, Monografia nr 875, Gliwice 2021.

9.2.2. Segmenting of ribbed axiso-asymmetric forgings

The peculiarity of the instrument work is the design of the upper punch, which consists of a series of segments associated with each other. The working movement of the punch segments that causes deformation of the material is carried out by the interaction of the rollers embedded in the sockets on the upper retaining part of the segments. Depending on the number of rolls, the deformation can be carried out simultaneously by the same number of segments. For example, the use of three rollers causes the simultaneous working movement of three segments. The other segments are not currently participating in the deformation. The number of punch segments is a multiple of the number of rolls, for example: for a system of 3 rollers, 6, 9, 12 segments are provided. The segmented construction of the punch and the kinematics of the tool movement cause a local zone plasticization of the material. Plasticized zones appear in the material sequentially in a number equal to the number of rollers used and with a frequency that depends on the rotational speed of the cast in which the rollers are embedded. The kinematic diagram of the instrument is shown in Figure 9.2.

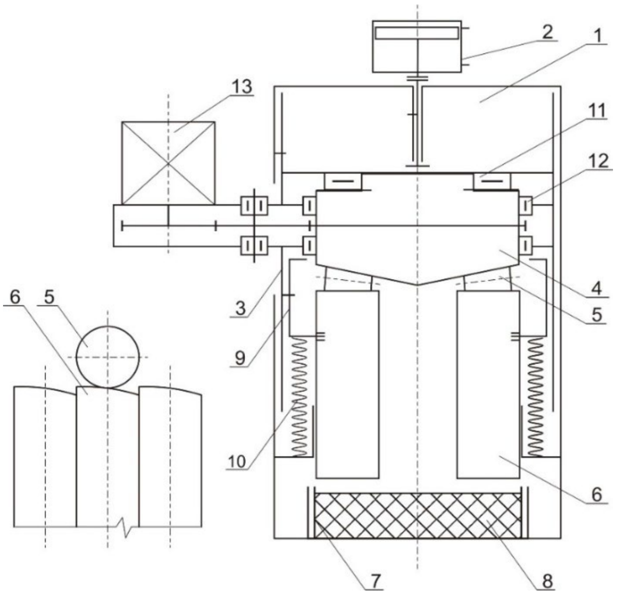

Fig. 9.2. Kinematic diagram of the compression device under the conditions of sequential local plastic deformation. 1. Body, 2. Hydraulic cylinder, 3. Slider, 4. Pressure plate, 5. Pressure roller, 6. Segmental punch, 7. Die, 8. Workpiece, 9. Guide ring, 10. Return spring, 11. Thrust bearing, 12. Radial bearing, 13. Drive

Rys. 9.2. Schemat kinematyczny przyrządu do ściskania w warunkach sekwencyjnego, lokalnego uplastycznienia. 1. Korpus, 2. Cylinder hydrauliczny prasy, 3. Suwak, 4. Talerz dociskowy, 5. Element toczny dociskowy, 6. Stempel segmentowy, 7. Matryca, 8. Materiał odkształcany, 9. Pierścień prowadzący, 10. Sprężyna powrotna, 11. Łożysko oporowe, 12. Łożysko poprzeczne, 13. Napęd

Source: Grosman F., Kurzydłowski J.K., Pawlicki J., Tomecki L.: Sposób kształtowania odkuwek i przyrząd do kształtowania odkuwek matrycą segmentową. Patent nr PL 210904 B1, 2012.

This way of realizing the deformation provides a significant reduction in the force necessary to shape. The total pressure of the press is accumulated on part of the surface of the deformed material, thus we obtain locally high values of unit pressures and the possibility of plasticizing materials characterized by significant plastic resistance. Thus, it allows you to effectively shape forgings in the form of rings, rings, ribbed wheels characterized by a large frontal surface and unfavorable from the point of view of shaping pressures small ratio of the height of the forging to the outer diameter. The high pressures found in traditional ways of shaping this type of forgings cause overloading of devices and the phenomenon of destruction of working tools, punches and dies. The tests were carried out on a simplified version of the instrument on a properly adapted press with a fluctuating matrix of the PXW-200 type. The hydraulic drive system of the PXW-200 was modified by introducing the main actuator speed control system. Figure 9.3 shows the individual elements of the prototype station in a six-anvil system[4]. The shaping tests of selected metal alloys were carried out on a model axis-asymmetric forging with recesses. Examples of forgings obtained in cold and hot forging tests of a model forging made of aluminum and titanium alloys are shown in Figure 9.4.

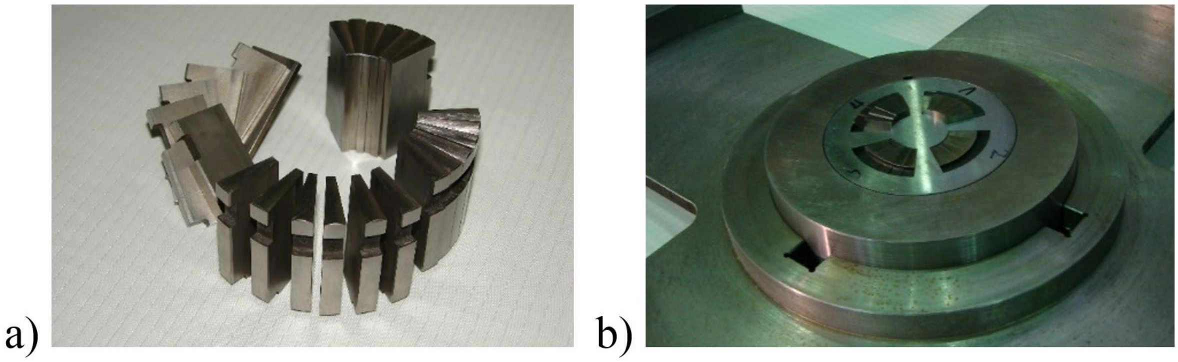

Fig. 9.3. Working segments in a system of 6 anvils (a) and segment head mount with segments (b)
Rys. 9.3. Segmenty robocze w układzie sześciu kowadełek (a) i głowica segmentowa z zamontowanymi segmentami (b)
Source: Grosman F., Pawlicki J., Ziółkiewicz S.: Kształtowanie segmentowe odkuwek ze stopów tytanu i aluminium. Hutnik. Wiadomości Hutnicze, t. 77, nr 8, 2010, s. 388–391.

---

[4] Grosman F., Pawlicki J., Ziółkiewicz S.: Kształtowanie segmentowe odkuwek ze stopów tytanu i aluminium. Hutnik. Wiadomości Hutnicze, t. 77, nr 8, 2010, s. 388-391.

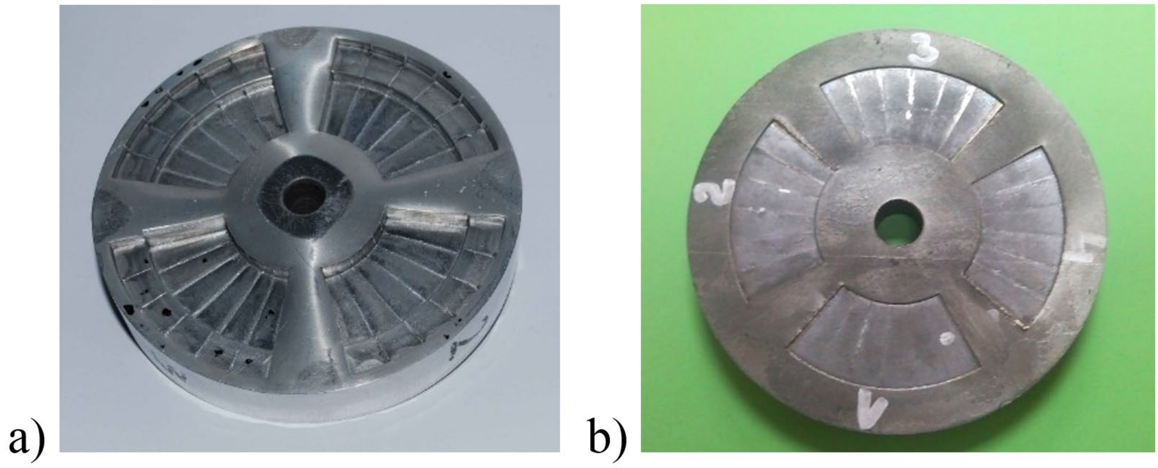

Fig. 9.4. Forging made of PA38 aluminum alloy cold formed (a) and forging made of WT3-1 titanium alloy formed at temperature of 900°C (b)
Rys. 9.4. Odkuwka ze stopu aluminium PA38 kształtowana na zimno (a) i odkuwka ze stopu tytanu WT3-1 kształtowana w temperaturze 900°C (b)
Source: Grosman F., Pawlicki J., Ziółkiewicz S.: Kształtowanie segmentowe odkuwek ze stopów tytanu i aluminium. Hutnik. Wiadomości Hutnicze, t. 77, nr 8, 2010, s. 388–391.

9.2.3. Segmentation of shell integral elements

Segmental shaping of longitudinal integral elements is carried out in the reciprocating movement of work rollers. The total surface of the shaped element is divided into sequential areas, locally plasticized during the process by tool segments. A diagram of the segmental shaping device for longitudinal integrals is shown in Figure 9.5[5]. The peculiarity of the construction of the instrument is the design of the upper punch, which consists of a series of segments associated with each other. The working movement of the punch segments causing the deformation of the material is carried out by pressing the rollers on the upper thrust part of the segments. The segmented construction of the punch and the kinematics of the tool movement cause local, zone plasticization of the material. Plasticized zones appear in the material sequentially in a number equal to the number of rollers used and with a frequency that depends on the speed of sliding movement of the rollers.

---

[5] Grosman F., Pawlicki J., Tomecki L., Kurzydłowski J.K.: Przyrząd do obróbki plastycznej matrycą segmentową. Patent nr PL 211137 B1, 2012.

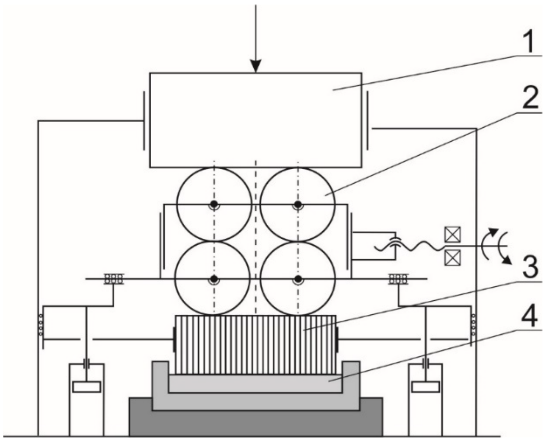

Fig. 9.5. A segmental forming device with reciprocating movement of the working rolls: 1. Press ram, 2. Rolls, 3. Segmental punch, 4. Workpiece

Rys. 9.5. Przyrząd do kształtowania segmentowego z posuwisto-zwrotnym ruchem rolek roboczych: 1. Suwak prasy, 2. Rolki, 3. Stempel segmentowy, 4. Materiał odkształcany

Source: Grosman F., Pawlicki J., Tomecki L., Kurzydłowski J.K.: Przyrząd do obróbki plastycznej matrycą segmentową. Patent nr PL 211137 B1, 2012.

The reciprocating movement of the rollers is carried out by means of an additional drive. The device allows for a stepless adjustment of the rollers the speed of displacement and the pressure force of the press. This way of realizing the deformation provides a significant reduction in the force necessary to shape. The total pressure of the press accumulates on part of the surface of the deformed material, thus obtaining locally high values of unit pressures and the possibility of plasticizing materials characterized by significant plasticizing stress.

Attempts to shape the segmented model integral element with recesses for aluminum alloy. The input material was an aluminum sheet with dimensions of 215 x 135 x 12 mm. A four-section stamp was used. There are 20 segments in each section. You can change the number of segments in a section as you wish. Segmental shaping tools and a ready-made model integral with recesses are shown in Figure 9.6.

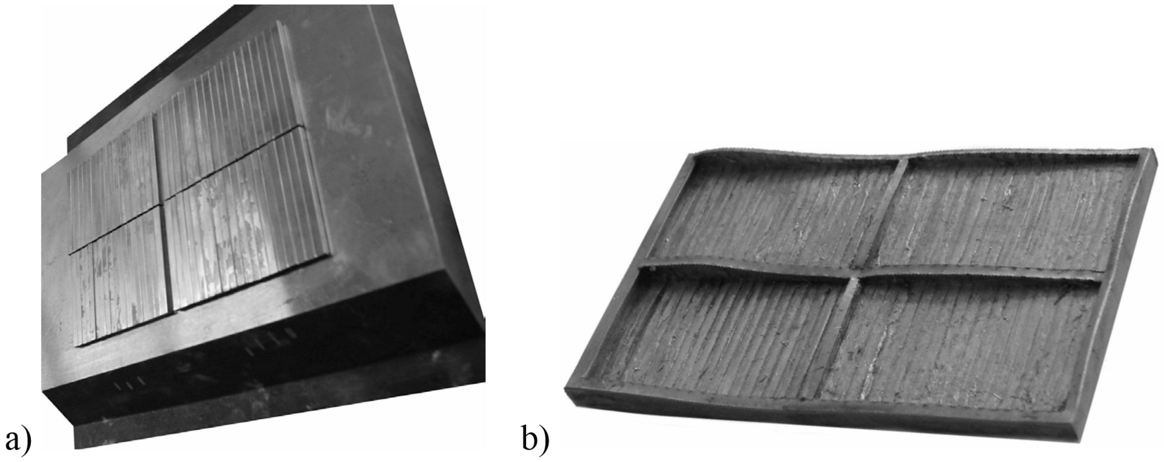

Fig. 9.6. Segments grouped in sectors within the punch frame (a) and the ribbed model element of aluminum alloy. Dimensions: 215 x 135 x 20 mm (b)
Rys. 9.6. Segmenty zgrupowane w sektorach wewnątrz oprawy stempla (a) i modelowy element użebrowany ze stopu aluminium. Wymiary: 215 x 135 x 20 mm (b)
Source: Grosman F., Pawlicki J., Ziółkiewicz S.: Kształtowanie segmentowe odkuwek ze stopów tytanu i aluminium. Hutnik. Wiadomości Hutnicze, t. 77, nr 8, 2010, s. 388-391.

On the surface of the recesses there are clear traces of the impact of individual segments. The height of the edges of the section of the element, ribs, is uneven and regularly corrugated, which is due to the diverse conditions of flow of plastic material. This phenomenon is defined by the principle of the least resistance to flow. Each point of the deformed body moves in the direction in which it encounters the least resistance. In technological practice, it is important to know the trajectory along which the resistance of plastic flow will be the smallest. When compressing with friction occurring in the contact zone of the frontal surface of the punch with the deformed material, the trajectory of the displacement of the points of the body is determined according to the principle of the shortest normal to the cross-section circumference.

The concept of the evolution of the development of segmental shaping technology also presents a solution in which working rollers affecting the shaping segments perform a sliding, peripheral, one-way movement (Fig. 9.1). This method of segmental shaping is designed for the manufacture of long elements with a repetitive, periodic structure of recesses along the length. The shaped element is moved during deformation on the press table relative to the position of the shaping mechanism. In this way, subsequent zones along the length of the element are deformed. The mechanism of movement of rollers due to their unidirectional movement is less technically complicated. However, this design solution requires a complementary technical analysis and assessment of implementation costs.

9.3. Volumetric shalping of forgings with oscillating torsion

The design of the device is an original technical solution covered by patent protection[6]. The technological device has been designed in such a way that the axial force is realized indirectly by a testing machine or a hydraulic press. The versatility of changing the location of the device and the possibility of using hydraulic systems of the strength of the testing machine or hydraulic press greatly simplify the construction of the device and reduce the cost of execution. The kinematic diagram of the device is shown in Figure 9.7.

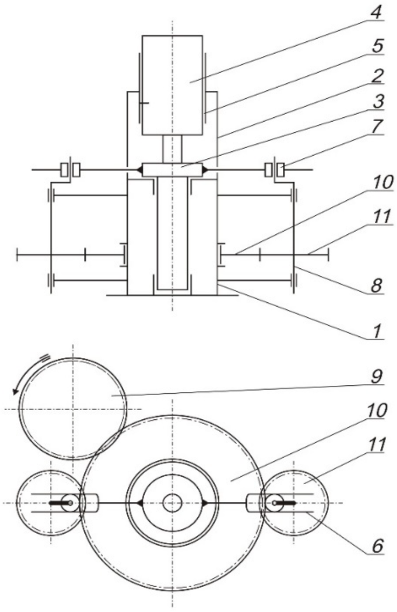

Fig. 9.7. Kinematic diagram of a compression device with oscillating torsion. 1. Lower body, 2. Upper body, 3. Lower punch, 4. Upper punch, 5. Non-rotating slidable bearing, 6. Fork − lower punch arm, 7. Roller, 8. Crankshaft (eccentric), 9. Driving gear, 10. Ring gear, 11. Gear wheel

Rys. 9.7. Schemat kinematyczny przyrządu do ściskania z oscylacyjnym skręcaniem. 1. Korpus dolny, 2. Korpus górny, 3. Stempel dolny, 4. Stempel górny, 5. Łożysko przesuwne nieobrotowe, 6. Widełki − ramię dolnego stempla, 7. Rolka, 8. Wał wykorbiony (mimośrodowy), 9. Koło zębate napędzające, 10. Pierścień zębaty, 11. Koło zębate

Source: Grosman F., Kurzydłowski J.K., Pawlicki J., Tomecki L.: Przyrząd do obróbki plastycznej metali. Patent nr PL 211139 B1, 2012.

---

[6] Grosman F., Kurzydłowski J.K., Pawlicki J., Tomecki L.: Przyrząd do obróbki plastycznej metali. Patent nr PL 211139 B1, 2012.

The device has the following possibilities of deformation tests of metallic materials and pressing of powders[7]:

- conventional compression in various friction conditions, e.g. frictionless compression, in dry friction conditions,
- conventional compression in a closed matrix with the possibility of adjustable radial metal flow,
- oscillating torsion (no postaxial movement of the upper punch),
- compression with simultaneous oscillating twisting under conditions of free radial flow of metal,
- compression with simultaneous oscillating twisting under high quasi-hydrostatic pressures,
- powder pressing by means of a pressing attachment mounted on the lower movable stamp.

The implementation of these shaping attempts is possible due to the additional kinematic function of the device, related to the oscillatory movement of the lower punch, which significantly increases the intensity of the given plastic deformations. The original kinematics of the device gives great possibilities of physical modeling of the structure of metals, implementation of tests of material sensitivity to changing the deformation path and practical application to conduct a technological swelling operation. The device in the process of work rests on the traverse of the testing machine. It has a smooth adjustment of the compression speed, torsion frequency and torsion angle amplitude. Kinematic quantity settings allow you to change the torsion angle in the range from 0° to ±8°. The frequency of fluctuations of the lower ft punch is regulated by an inverter in the range from 0 to 1.8 Hz with the possibility of increasing the maximum frequency to 2.6 Hz.

9.3.1. Mechanical and structural effects of the process

The results of studies carried out on a representative group of metallic materials showed that both a decrease in the compression velocity v_c, while maintaining a constant

---

[7] Pawlicki J., Grosman F.: Charakterystyki materiałowe dla oscylacyjnego skręcania. Prace Naukowe Politechniki Warszawskiej, z. Mechanika, nr 201, 2003, s. 139–144; Pawlicki J., Grosman F.: Analysis of power-energy effects for processes with forced deformation path. Archives of Civil and Mechanical Engineering, Vol. 4, No. 3, 2004, p. 45–55.

twist frequency f_t, and an increase in the frequency of twisting f_t, at a constant compression velocity v_c cause a decrease in the level of average unit pressures[8]. It can be concluded from this that the course of the force characteristics in the compression process with oscillating twisting is mainly determined by the ratio of the torsion angle to the increase in the crease Δh. The ratio of component deformation, caused by twisting to component deformation, caused by compression, is a parameter characterizing the path of deformation (d_ε), which determines the structural and force effects of deformation. Changing the process parameters, thus the proportion of the component deformations, results in the rotation of the main axes of the stress state and a change in the value of the main stresses. The stress state scheme also changes along the radius of the cylindrical sample and in the axis of the sample for $r = 0$, corresponds to the uniaxial state of stress $\sigma_1 > 0$, and the remaining principal stresses $\sigma_2 = \sigma_3 = 0$. When considering the force parameters in the axis of the sample $F, > 0$ and $M_t = 0$.

Figure 9.8 shows the course of the mean unit loads obtained during compression, under conditions of change of the strain path during the test. The additional oscillating movement of the lower punch causes a marked decrease in the amount of pressure in any phase of the compression process. The mean unit pressure remains constant with increasing crease and for the corresponding value of the actual crumb $\varepsilon = 1.1$ (logarithmic deformation) is almost 100 MPa less. Stopping during the oscillating twist test produces the opposite effect, an immediate increase in pressures that reach the level of conventional compression pressures.

---

[8] Rodak K., Pawlicki J.: Effect of compression with oscillatory torsion processing on structure and properties of Cu. Journal of Materials Science and Technology, Vol. 27, 2011, p. 1083–1088; Rodak K., Pawlicki J.: Microstructure characterization of Cu processed by compression with oscillatory torsion. Materials Characterization, Vol. 94, 2014, p. 37–45; Rodak K., Pawlicki J.: Efficiency of the compression with oscillatory torsion method in grain refinement in Al. Archives of Civil and Mechanical Engineering. Vol. 16, 2016, p. 805–812.

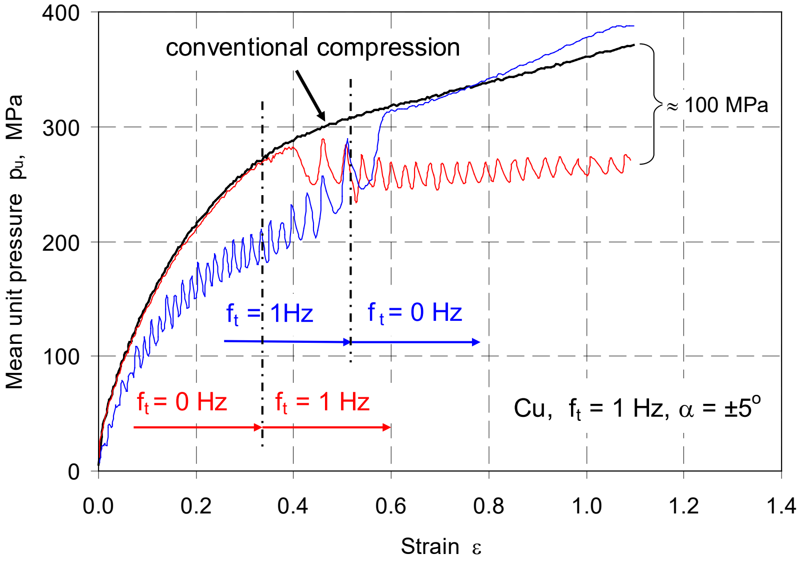

Fig. 9.8. The effect of strain path on mean unit pressure values for cylindrical copper samples subjected to compression with oscillatory torsion

Rys. 9.8. Wpływ drogi odkształcenia na wartość średnich nacisków jednostkowych w próbie ściskania z oscylacyjnym skręcaniem próbek walcowych z miedzi

The compression process with oscillating twisting causes certain structural effects in the material. Their nature and intensity of occurrence depend on the set kinematic parameters of the process and the amount of cumulative deformation (total replacement deformation). Figure 9.9 shows the effect of fragmentation of the material structure (Cu) resulting from a change in process parameters and, consequently, an increase in total replacement deformation[9]. The high intensity of deformation and the dynamics of the process cause that this process is heat-activated in microareas. In order to obtain unambiguous results for such a complex deformation process, an area representative of microstructural studies was selected from the center of the height of the cylindrical sample at a distance of approx. 0.8 of the sample radius.

---

[9] Rodak K., Pawlicki J.: Microstructure characterization of Cu processed by compression with oscillatory torsion. Materials Characterization, Vol. 94, 2014, p. 37–45.

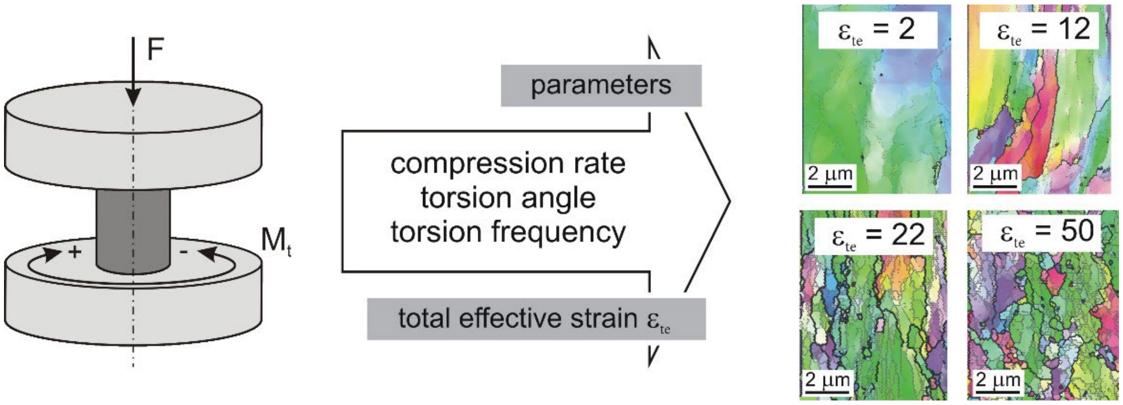

Fig. 9.9. Influence of process parameters on the total equivalent deformation ε_{te} and the grain grinding effect

Rys. 9.9. Wpływ parametrów procesu na całkowite odkształcenie zastępcze ε_{te} i efekt rozdrobnienia ziarna

Source: Rodak K., Pawlicki J.: Microstructure characterization of Cu processed by compression with oscillatory torsion. Materials Characterization, Vol. 94, 2014, p. 37–45.

An interesting phenomenon accompanying the compression process with oscillating twisting is the shape of the samples after deformation. Figure 9.10 shows the view of copper samples after compression with oscillating twisting and conventional compression under dry friction conditions[10]. Shape of compressed samples with oscillating torsion it is similar to the geometry of cylindrical samples compressed in frictionless conditions. The lack of pronounced sphericity of the surface forming the cylindrical sample (barrel-likeness) indicates that the resulting deformations in the volumes of compressed samples are uniform. A similar effect of the lack of sphericity of the surface forming cylindrical samples was also found for a significant group of test materials (Al, steel grade 0H18N9, titanium alloy Grade 1)[11].

---

[10] Rodak K., Pawlicki J.: Effect of compression with oscillatory torsion processing on structure and properties of Cu. Journal of Materials Science and Technology, Vol. 27, 2011, p. 1083–1088.

[11] Rodak K., Pawlicki J.: Microstructure of ultrafine-grained Al produced by severe plastic deformation. Arch. Mater. Sci. Eng., Vol. 28, No. 7, 2007, p. 409–412.

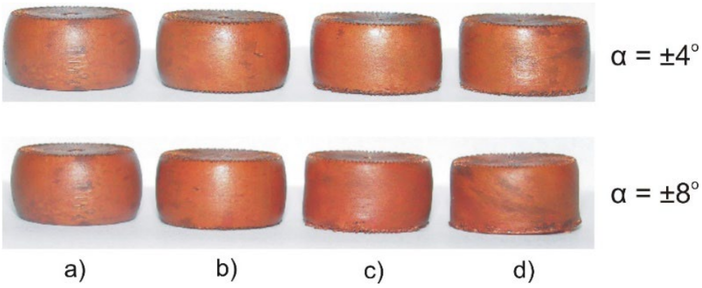

Fig. 9.10. A view of samples subjected to oscillatory torsion with strain rate of $v_t = 0.6$ mm/s for torsion angles $\alpha = \pm 4°$ and $\alpha = \pm 8°$: a) a sample compressed without torsion, b) $f_t = 0.4$ Hz, c) $f_t = 1$ Hz, d) $f_t = 1.8$ Hz

Rys. 9.10. Widok próbek po ściskaniu z oscylacyjnym skręcaniem z prędkością ściskania $v_t = 0,6$ mm/s dla kątów skręcania $\alpha = \pm 4°$ i $\alpha = \pm 8°$: a) próbka ściskana bez skręcania, b) $f_f = 0,4$ Hz, c) $f_f = 1$ Hz, d) $f_f = 1,8$ Hz

Source: Rodak K., Pawlicki J.: Effect of compression with oscillatory torsion processing on structure and properties of Cu. Journal of Materials Science and Technology, Vol. 27, 2011, p. 1083–1088.

9.3.2. Model die forging process

The conducted compression tests with oscillating twisting supported the activities aimed at developing a model forging process of matrix forgings of osivosymmetric forgings with a reversibly torsional lower matrix. In industrial conditions, this process corresponds to the process of die forging in an open matrix (with an outflow). Figure 9.11 shows the process diagram and spatial visualization of the tools. The basic assumption that determines the effectiveness of this method of deformation is the selection of the forging shape, which will allow the transfer of a variable cyclically twisting torque at the height of the charge. The input material for forging should have at both ends an appropriate cross-section (square, triangular, etc.), associated with the parts of the blank in the lower and upper matrix. Another way is to conduct the initial forging phase without reversible movement of the lower matrix until the selected lower part of the blank (e.g. with a square cross-section) is filled, which will allow the transfer of cyclically variable twisting torque to the material in the further phase of the forging process, but already with the reversible movement of the die running. In the deformation process, to initiate the beneficial effects of additional deformation of the form from twisting, it is necessary to perform at least one full twisting cycle.

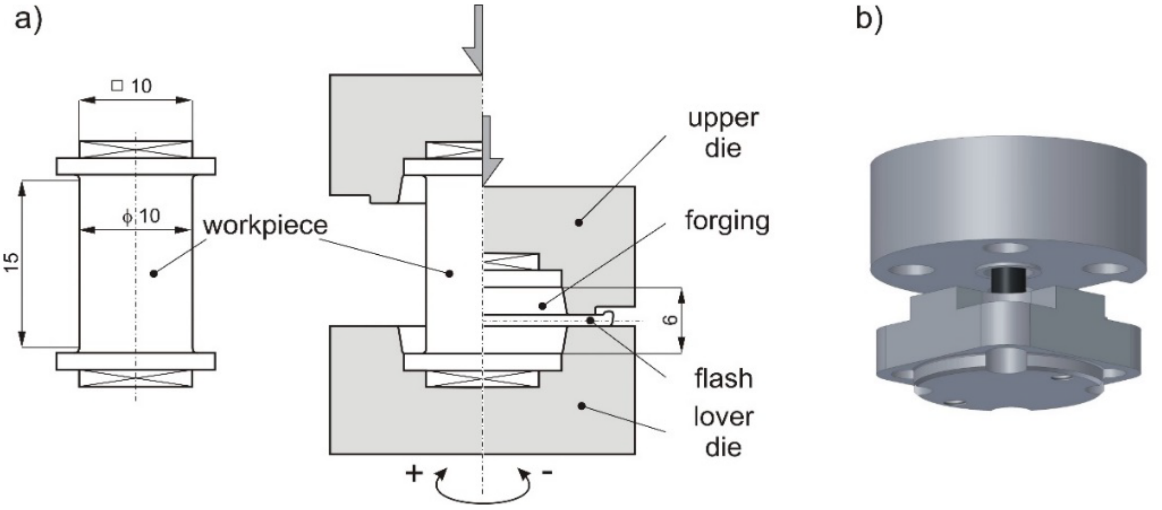

Fig. 9.11. Scheme of the compression process with a reverse torsion bottom die (a) and spatial visualization of tools (b)
Rys. 9.11. Schemat procesu ściskania z rewersyjnie skrętną dolną matrycą (a) i wizualizacja przestrzenna narzędzi (b)

The most effective solution, as well as the one that can cause the effect of uniform deformation in the volume of the forging, is the simultaneous torsional movement of both dies, upper and lower. However, such a solution further complicates the design of the device. In a conventional die forging process, one of the dies is stationary, so it is easier to develop and install an additional mechanism to actuate torsional movements in the lower die.

One of the possibilities of using the new shaping method is forging the heads of bolts and screws, special fasteners for the mining industry and the construction of railway infrastructure.

9.3.3. Plastic shaping of metals supported by additional shear stresses

The concept of plastic shaping supported by additional shear stresses is a derivative of work and research carried out on a compression device with oscillating twisting. The compression process with oscillating twisting can be used for cylindrical samples, in industrial applications of axesymmetric forgings such as disc, ring, disc, etc. The high efficiency of the process as well as the ability to control the structure of the material to obtain the desired strength and functional properties were the basis for the development of the assumptions of the concept of the station for the production of forgings with an elongated shape based on the same method of loading. As a result, two concepts for the drive of the reciprocating movement of the lower matrix, based on the eccentric mechanism and hydraulic cylinders, were developed. Both studies are the subject of a patent[12].

Figure 9.12 shows a modification of the instrument consisting in the use of two hydraulic cylinders (5, 6) to drive the lower punch (3) and setting in an oscillating reciprocating motion. This structural solution for instrument construction is less mechanically complicated and easier to perform. The design of the instrument is also more compact, which can be important when placing the instrument on the table of the hydraulic press.

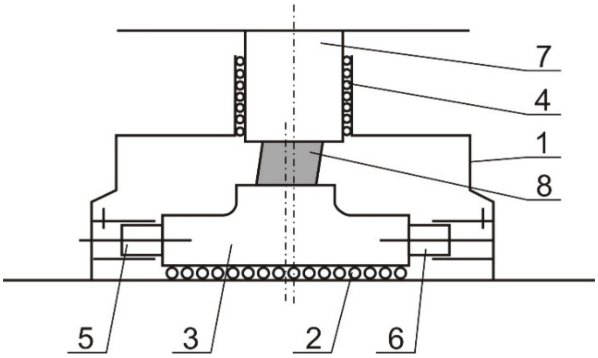

Fig. 9.12. Scheme of the compression device aided by additional shear stresses: 1. Body, 2. Float guide, 3. Lower punch, 4. Float guide, 5. Left hydraulic cylinder, 6. Right hydraulic cylinder, 7. Upper punch, 8. Workpiece

Rys. 9.12. Schemat przyrządu do ściskania wspomaganego dodatkowymi naprężeniami ścinającymi: 1. Korpus, 2. Prowadnica toczna, 3. Stempel dolny, 4. Prowadnica toczna, 5. Cylinder hydrauliczny lewy, 6. Cylinder hydrauliczny prawy, 7. Stempel górny, 8. Materiał odkształcany

Source: Grosman F., Kurzydłowski J.K., Pawlicki J., Tomecki L.: Sposób plastycznego kształtowania wyrobów metalowych i przyrząd do plastycznego kształtowania wyrobów metalowych. Patent nr PL 211138 B1, 2012.

This method of shaping the plastic material consists in simultaneous compression and oscillating form deformation in the direction perpendicular to the direction of pressure of the punches. As a result of such a movement of tools, the material compressed between the punch and the die is subjected to cyclic loading with a transverse force causing the occurrence of additional shear stresses in the deformed material, which improves the conditions for filling the die blanks, resulting in the effect of “closing” and “bonding” material discontinuities and changing the structure and

---

[12] Grosman F., Kurzydłowski J.K., Pawlicki J., Tomecki L.: Sposób plastycznego kształtowania wyrobów metalowych i przyrząd do plastycznego kształtowania wyrobów metalowych. Patent nr PL 211138 B1, 2012.

properties of the material. The end result of such a process is to reduce the number of deficiencies in the production of products and semi-finished products resulting from the local effects of loss of material consistency.

Plastic shaping supported by additional shear stresses, allows to obtain a number of new effects in terms of geometric features and the quality of manufactured products. The main advantage of this method of manufacture is the possibility of obtaining products with a lower relative height (ratio of height to transverse dimension) and a homogeneous and fine-grained structure. This method can be used mainly for the production of machine components with very high static, dynamic and fatigue strength. It is particularly suitable for the manufacture of high-power motor components, pumps and gearboxes, and components for medicine (homogeneous material structure and high strength).

9.4. Rolling process with the cyclical, axial movement of rollers

Rolling with Cyclic Movement of Rolls (RCMR) can be an interesting and competitive alternative to the well-known methods of large plastic deformation SPD (Severe Plastic Deformation). A big advantage of the process is the possibility of quick application in industrial conditions for the production of ultra-bottom-grained materials and nanocrystalline. The device was made on the basis of an unconventional technical solution of the movement of shaping tools and equipped with a complete measuring system recording all parameters of the process course.

The RCMR rolling station is designed in a duo roller system. The mechanism of post-axial movement of rollers is the original design solution of the experimental rolling mill[13]. The rolling process carried out in this way is characterized by the possibility of obtaining much higher effective deformation values. The RCMR process differs from conventional rolling by the additional transverse movement of the rollers. The band is deformed by simultaneously reducing the height and forced movement of the layers of material in a direction perpendicular to the main direction of rolling. In the conventional rolling process, the height of the band is reduced (crease) and the flow of material in the direction perpendicular to the direction of rolling (widening) is insignificant. Figure 9.13 shows the kinematic diagram of the device in the RCMR process.

---

[13] Grosman F., Pawlicki J., Korbel A., Bochniak W., Kiełpiński R., Tomecki L.: Sposób walcowania, zwłaszcza metali oraz klatka walcownicza do walcowania, zwłaszcza metali. Patent nr 203220 B1, 2009.

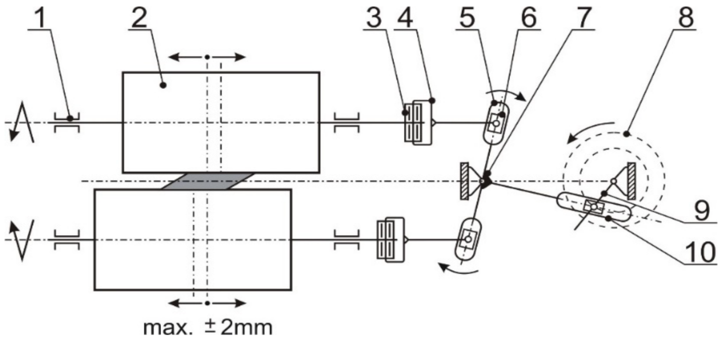

Fig. 9.13. Scheme of the setup of RCMR. 1. Bearing, 2. Working roll, 3. Thrust bearing, 4. Hushing, 5. Yoke, 6. Stone sliding, 7. Swivel, 8. Eccentric bush, 9. Eccentric shaft, 10. Stone sliding

Rys. 9.13. Schemat kinematyczny urządzenia RCMR. 1. Łożysko, 2. Walec, 3. Łożysko wzdłużne, 4. Obudowa, 5. Jarzmo, 6. Kamień ślizgowy, 7. Czop, 8. Tuleja mimośrodowa, 9. Wał mimośrodowy, 10. Kamień ślizgowy

Source: Grosman F., Pawlicki J., Korbel A., Bochniak W., Kiełpiński R., Tomecki L.: Sposób walcowania, zwłaszcza metali oraz klatka walcownicza do walcowania, zwłaszcza metali. Patent nr 203220 B1, 2009.

The implementation of the axial movement of the rollers is forced by a pendulum built on pins 7 yoke 5, which alternately affects the working rollers 2 moving them along their axis. Yoke 5 is set in motion through an eccentric system consisting of an eccentric shaft 9 and an eccentric sleeve 8, which cyclically move yoke 5. This cyclic movement of yoke 5 is transmitted to the housings of 4 bearings 3 and through the two-way thrust bearing 3 on the working rollers 2. The magnitude of the postaxial movement of working rollers 2 is regulated by changing the position of the eccentric sleeve 8 on the eccentric shaft 9. The eccentric sleeve 8 is adjustable relative to the eccentric shaft 9 as a result, so the resultant eccentricity can vary from zero to the sum of partial eccentricities. This allows for a smooth adjustment of the deflection of the yoke of 5, and thus a smooth and stepless axial movement of the working rollers 2.

The design of the device allows quick replacement of rollers, setting the gap between the rollers and the desired size of the axial stroke of the rollers. Adjustments and settings of the device allow to change the deflection of the cylinder from the central position to ±2 mm and the frequency of transverse fluctuations of the rollers up to 3 Hz. The transverse deformation of the band is forced by parallel grooves made on the surfaces of the roller barrels. The device is equipped with a measuring system from BMCM − Germany. The measurement system is controlled, processed and stored using NEXT VIEW 3.4. program.

9.4.1. Mechanical and structural effects of the process

In the RCMR rolling process, it is possible to perform large total plastic deformations. The amount of deformation accumulated in the material (rolled band) depends on the number of culverts and can be adjusted. The process also has no limits on the geometric sizes of the input material, which distinguishes the RCMR method from other methods of large plastic deformations. It is practically possible to continuously deform a band of any length, which gives the method a practical and industrial character.

Figure 9.14 shows the effect of the number of culverts (single deformations) on the total deformation value in the conventional rolling process and RCMR[14].

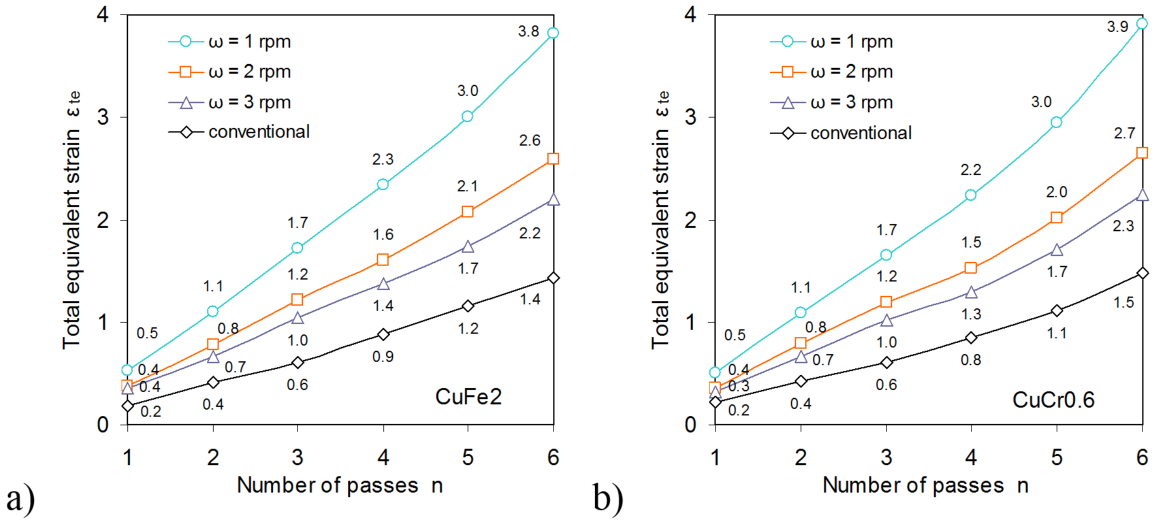

Fig. 9.14. Influence of rolling speed on the value of total equivalent strain depending on the number of passes n, with a constant displacement amplitude transverse rollers A and frequency f: a) CuFe2 alloy, b) CuCr0.6 alloy

Rys. 9.14. Wpływ prędkości walcowania na wartość całkowitego odkształcenia zastępczego w zależności od liczby przepustów n, przy stałej amplitudzie przemieszczenia poprzecznego walców A i częstotliwości f: a) stop CuFe2, b) stop CuCr0,6

Source: Płachta A., Pawlicki J.: Wpływ procesu walcowania z poosiowym, cyklicznym ruchem walców na strefy lokalnych odkształceń w stopie CuFe2. Rudy i Metale Nieżelazne, R. 60, nr 11, 2015, s. 559–563.

The resulting value of total deformation after 6 culverts in the RCMR process is about 2.5 times higher than that obtained in the conventional rolling process. This result was obtained for the rotational speed of the rollers ω = 1 rpm. The total replacement

---

[14] Płachta A., Pawlicki J.: Wpływ procesu walcowania z poosiowym, cyklicznym ruchem walców na strefy lokalnych odkształceń w stopie CuFe2. Rudy i Metale Nieżelazne, R. 60, nr 11, 2015, s. 559–563.

strain values for speeds ω = 2 rpm and ω = 3 rpm are correspondingly lower. This regularity is due to a decrease in the number of postaxial movements of the rollers along the length of the rolling basin with an increase in the rotational speed of the rollers (rolling speed). The value of the total replacement deformation in the RCMR process is defined as the mean value of the deformation over the length of the rolling basin.

Observations of the structure of cross-sections of bands in subsequent culverts in the RCMR process, they indicate a significant impact of the additional transverse movement of the rollers on the evolution of local deformation zones. Figure 9.15 shows microstructural images of the cross-sections of the samples for selected culverts.

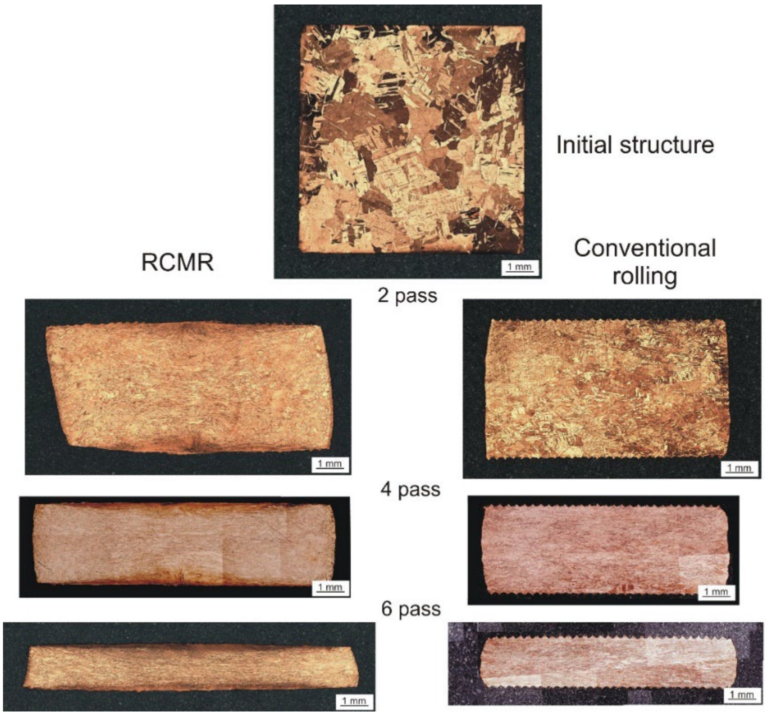

Fig. 9.15. Microstructural images of sample cross sections in selected passes in the RCMR and conventional rolling process

Rys. 9.15. Obrazy mikrostrukturalne przekrojów poprzecznych próbek w wybranych przepustach w procesie RCMR i w procesie walcowania konwencjonalnego

The transverse, cyclic movement of the rollers already causes in the initial phase of deformation (in the initial culverts) the formation of zones strongly deformed at the contact surfaces with the upper and lower rollers. Near-surface intensively deformed zones migrate in subsequent culverts from the surface towards the center of the band and cover an increasing volume of the band. The effectiveness of the influence of rollers on the size and location of large plastic deformations increases with the number of culverts.

Studies of hardness distributions (HV0.2) on cross-sections of samples showed the convergence of results with zones of local intense deformations. In the RCMR process, high hardness values occur in zones near contact with the upper and lower rollers. In the process of conventional rolling, the hardness distribution is more even over the cross-section of the band. Areas with a high hardness value occur throughout the entire cross-section of the sample. In the sample formed in the RCMR process, the hardness values are lower in the zones of intensive plastic deformation, although the total replacement deformation is much greater than that obtained in the conventional rolling process.

The deformation softening effect observed in the RCMR rolling process is caused by a permanent change in the load scheme. This phenomenon has already been observed in laboratory studies and technological processes, where the change in the orientation of the main stresses is revealed by a decrease in the hardness of the materials in the area of the center of the deformation basin. The phenomenal analysis of the specific mechanism of plastic deformation of metals under the influence of external conditions, as a result of cyclical forcing and a change in the path of deformation, was carried out by A. Korbel[15].

The effect of softening of the deformation is also visible on the unit pressure waveforms of the rolling. Figure 9.16 shows examples of the characteristics of the average unit loads of rolling in the RCMR and conventional rolling processes. The level of pressure in the RCMR process in subsequent culverts is significantly lower compared to conventional rolling. The phenomenon of a decrease in rolling pressure is independent of the type of material, which has been confirmed by laboratory studies carried out on a large number of metals. The power and energy analysis of this issue is the subject of further experimental research supported by the assessment of thermal effects using a thermal imaging technique.

---

[15] Korbel A.: Structural and mechanical aspects of localized deformation in Al-Mg alloy. Arch. Metall. 32, 1987, p. 377–392; Korbel A., Martin P.: Microstructural events of macroscopic strain localization in prestrained tensile specimens. Acta Metall. 36, 1988, p. 2575–2586.

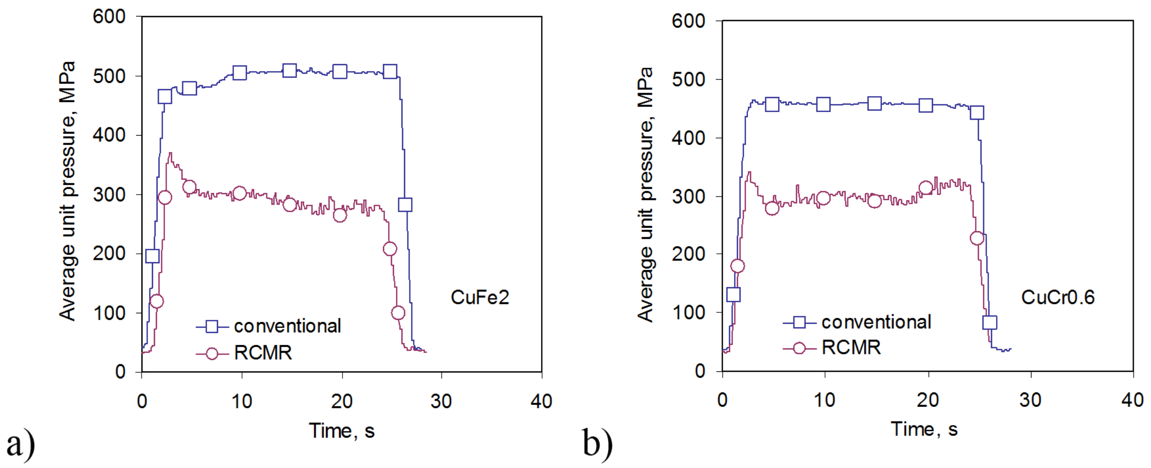

Fig. 9.16. Characteristics of average unit pressures of rolling in the 5th pass for CuFe2 (a) and CuCr0.6 (b)
Rys. 9.16. Charakterystyki średnich nacisków jednostkowych walcowania w 5 przepuście dla CuFe2 (a) i CuCr0,6 (b)

9.5. Summary

The positions presented in the work are unique in the world of research and technological devices and can be the basis for the launch of a new technology in industrial conditions. The knowledge and practical application of the strength and structural effects of new shaping methods can significantly change the current perception of the directions of development of plastic processing technology.

The use of the presented technologies will allow more effective control of the microstructure and properties of products in the stages of their production and processing. This issue is particularly important in the situation of using new construction materials in the construction of means of transport, m.in new generation high-strength body steels and light metal alloys. In laboratory and technological tests, high efficiency of grain grinding methods has been demonstrated also on the nanometric scale. In the methods there are large reserves in terms of modifying the structure of metals and obtaining controlled mechanical properties.

Segmented shaping is primarily a higher material yield resulting from the replacement of material-intensive machining with machining. It also possible to produce monolithic integral coatings and front forgings with a favorable course of material fibers according to the shape of the element. It is also allows for the possibility of producing monolithic integral coatings and front forgings with high-strength ribbing and favorable fiber flow of the material in accordance with the shape of the element. In addition to increasing the level of strength properties, the method allows reducing the weight of the product, reducing the number of joints, thus places of stress concentration and sources of crack generation, which affects the durability and improvement of safety. In the technological process, it is possible to reduce the number of operations and quickly adapt the existing machine park, thus reducing investment outlays.

The compression method with oscillating torsion is particularly effective in the production of die forged products. The uniform distribution of deformations in the volume of the forging, significant cumulative deformations, and high strength indicate the possibility of using the method for the production of forgings such as a disc, disc, also used in the construction of vehicles as well as fasteners of railway infrastructure, heads of railway screws and screws for the mining industry.

The rolling process with cyclic, axial movement of rollers is a technology that can be used in large-scale and mass production, with high efficiency, which puts the process in a convenient implementation situation. The most important benefits of its use are, above all, obtaining a large total deformation, the desired and controlled structure of the material, and shortening the production cycle of rolling by reducing the number of component operations (the number of culverts). It is possible to produce sections with a gradient structure, also ultrafine-grained and nanometric and production of, for example, conductive copper alloy rails used in the construction of electromobile means of transport and elements of energy railway infrastructure. Due to the occurrence of large, cyclically variable shear stresses that effectively penetrate the band at height, the method can be used in the recycling processes of layered composite materials.

The presented unconventional plastic shaping have a not yet fully recognized, application potential. However, the level of advancement of research and technological tests is sufficient to take action to implement new methods of plastic processing in industrial conditions.