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Putting into practice innovative potential in the universal radial-shear rolling process

Various mini-mill structures of new generation for implementation of multiple-purpose radial-shift rolling (RSR) are described. Deep compaction and metal structure development throughout all the levels of the metal-physical morphology take place during helicoidal metal outflow along the prescribed trajectories with deceleration of the outer layers of stock material and acceleration of the inner ones creates intensive shift displacements in the deformation zone. As for morphological structure, it is shown that the metal becomes a material of new quality after RSR. Principal improvement physical and mechanical metal properties are noted on the permanent base. The best results are reached in plastic and viscous performance properties as well as in those, which are correlation-associated with them. A number of highly-effective innovative technics of deformation processing of miscellaneous metals and alloys, such as deep metal structuring and improvement of its properties in elongated volumes by intensive plastic straining; creation of automatic complexes of thermo-mechanical processing; return to the economic circulation (recycling) of out-of-service rods and off-gage bar-profiled residual

portions; production of stock materials of optimum diameter for piercing with improvement of the continuously-cast product structure and toughness, are presented.

Key words: deformation impact, combining, plastic deformation, carbon wire, tension, compression, bending, twisting, ultrafine grain structure, mechanical properties.

The present-day classification of metal forming processes defines the radial-shear rolling (RSR) as a special case of stationary screw rolling in the field of the big feed angles (15–18° and more) in rolls with special calibration for uniform cross-section solid billet working [1].

The RSR special-purpose designation is the effective production of round bars, rods, and rough workpieces mainly of alloyed metals and alloys; formation of unique metal structure by its deep structure processing in elongated volumes; RSR has opened essentially a new way to bar-rolling and tube production updating as well as solution of some actual problems concerning thermo-softening processing.

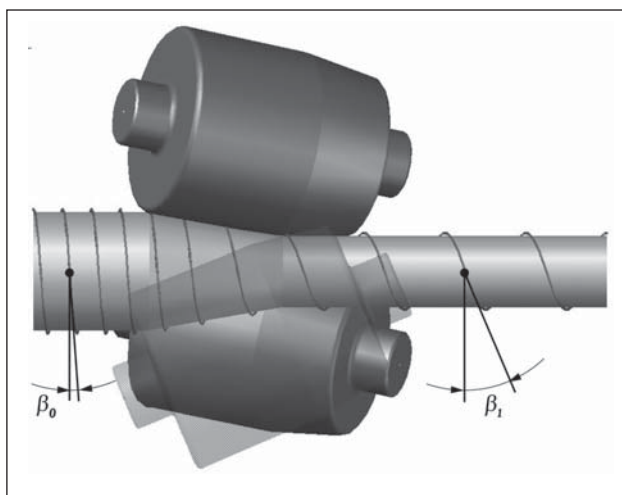


Fig. 1. RSR diagram for determination of rational strain conditions

Radial-shear rolling implemented as a form of the universal method is characterized by a special efficiency [2]. The technical literature covers the information on the universal method completely enough but discretely. This defines the actuality of present, more regular narrative.

The technological basis of the universal RSR process is of investigation reaching of the internal metal-flow-trajectory geometry invariance necessary for zero-defect rolling of practically any deformable materials. The metal stress and strain state diagram and the billet rolling ability during RSR is controlled by screw trajectory pitch angles β_m (**Fig. 1**). The rational conditions are realized if the minimum β_0 value in the deformation zone is no less than 10–15° and the surface trajectory pitch angle β_1 at the roll exit is 16–24°.

The given condition has a criterion character and practically does not depend on the properties of rolled metal and billet diameter. This allowed us to synthesize the universal rolling method (**Table 1**, **Fig. 1**) providing stable rolling in a wide interval of billet diameters (14–500 mm) and reduction (1.01–3.00) without problems

concerning quality. The method has no restrictions on the biting conditions, roll pass filling, workpiece stability, and the number of proceeded passes.

The three-dimensional geometry of the universal method is based on big roll feed angles of 16–24°, rolling angles of 7–15° and roll calibration in which the breaking-down section is made in the form of a cylinder or a flattened cone with small taper angle. For finer adjustment by the defloration conditions, the application of multitapered sizing is possible as well.

On November 15, 1977 the universal method of RSR has been tested on MISiS-100T mill in rolling the billets of refractory KhN77TYuR and KhN51VMTYuKFR nickel alloys. The billets in diameter of 105 and 120mm were rolled to a bar in diameter of 55mm during 5 and 7 passes. Then for the first time in the world practice a pilot lot of ingots was rolled, which were preliminarily deformed, as well as continuously-casted billets of high-alloyed low-ductility 45Kh14N14V2M, Kh12M, R6M5, R18 steels, difficult-to-form refractory KhN-55VMTFKYu, KhN56VMTYu alloys, etc.

In rolling, a set of working rolls with the universal roll-pass design was applied to allow us to roll with a free choice of reduction with unrestricted number of passes. Up to now, already more than thirty five years, the method remains unsurpassed as to the efficiency, versatility, and accessibility of realization. In 1978, MISiS-100T mill has been updated and became the first-ever reversing mill of radial-shear rolling. Later the method became a technological ground of screw rolling mini-mills as well [3]. The large-scale introduction of RSR has begun with production of responsible rolled products for aircraft, nuclear power industry, and chemical machine-building industry.

Later the method became a technological ground of radial-shear (screw) rolling minimills as well. Two species of mini-mills with:

- Axial adjustment of working rolls without constructive feed angle, which are installed under rolling angle and with transverse eccentricity [3];

- Radial adjustment of rolls with wedge screw-down mechanism [4]

succeeded the greatest spread.

A principal arrangement of the first type mini-mills is presented in **Fig. 2**. Appearance of the mill is shown in **Fig. 3**.

A rolling mill consists of reduction mill 1, individual principal drives of mill rolls 2, input 3 and output 4 sides. Reduction mill 1 includes a frame in the form of two supports-plates 5 fixed on the flat foundation 6 and joined by rods 7; three cartridges 8 with mill rolls 9 located round the mill axis through 120°; mechanisms of axial advance to approach-removal of the cartridges with rolls along guide rods 11.

Mill rolls 9 are fixed on two bearing assemblies in cartridges 8, which by means of

Table 1. Parameters of universal method of radial-shear rolling [2]

Parameter	Unit measure	Value
Number of work rolls		3
Rolling diagram (rolling angle sign δ)	(–) (±)	cup-shaped or reverse cup-shaped–mushroom-type
Surface trajectory pitch angle at the exit out of rolls	degree	16–24
Rolling angle module	degree	7–15
Roll generatrix inclination to rolling axis along the reduced section, α	degree	$\alpha = (0.7–1.5) \delta $ or 12 ± 5
Angle of roll taper at sizing section	degree	min ($\leq \delta $)
Reduction per pass, μ	–	$1.05 \leq \mu \leq 4.0 \dots 4.5$
Roll sizing section length to roll metal diameter ratio		0.5–1.5
Roll diameter to billet diameter ratio	–	2.0–5.5
Initial rolling temperature	°C	$T_{\text{melt.max}} - (20–100)$ $T_{\text{roll.prod.}} - (20–100)$

through-holes are fixed on the guide rods 11 made in the form of cylindrical rods parallel to the roll axis. Adjustment of the rolls to working pass is axial and is executed by movement of the cartridges with the rolls along their axes in the planes parallel to the mill axis and tangentially spaced from it by constant value ϵ . Adjustment of cartridges with the rolls to the preset roll pass is made by rotation of screws of the axial advance mechanism.

The second type mini-mill arrangement is illustrated by the example of «14-40» mini-mill (Fig. 4).

The reduction mill of a mini-mill (Fig. 5) includes a fixed external casing 1 in which mobile shoe 2 is arranged with the opportunity of axial movement. Cartridges 3 with work rolls 4 are placed in the radial boring of shoe 2. Cartridges 3 are fastened to casing 1 with spring-biased rods 5 through slots in shoe 2. Shoe 2 is fitted with by an axial movement drive from gear motor 10 with rods 9. Run-in chute 6 and run-out chute 7 maintain the rod on the rolling axis. All the design is installed on base plate 8.

The principal distinctive feature of the mini-mills of both types consists in that the optimum technological parameters of the RSR process (feed and rolling angles, deformation zone geometry, flow trajectories, etc.) are integrated directly into the reduction mill structure. It drastically raises the reliability of the rolling-mill machinery for guaranteed execution of the preset trajectory-speed conditions of radially-shearing deformation.

Developing its powerful innovative potential, the universal RSR method and mini-mills of a new generation, successfully solve actual problems of plastic deformation of metals and find new fields of their industrial application.

The studies of the last years have shown prospectivity of metals with ultrafine grained structure as constructional and functional materials of a new generation with a qualitatively new complex of properties. One of the fine structure crushing methods includes carrying-out of so-called severe plastic deformation (SPD). Equal-channel pressing processes, sinking strain with torsion, and screw extrusion are most often proposed as means for SPD. These methods are of little use for technical application because they have the lowest productive capacity and complex tools. None of these processes allow us to produce hardware items acceptable in shape and overall dimensions for subsequent practical use.

Initially, RSR was positioned as a method of severe plastic deformation for deep metal structurization of elongated articles of bar and tube type. The trajectory-speed conditions of RSR deformation are unique. They ensure deep processing of metal structure at all levels of metal-physical morphology including the nano-level.

The helicoidal metal flow along the preset trajectories with deceleration of external

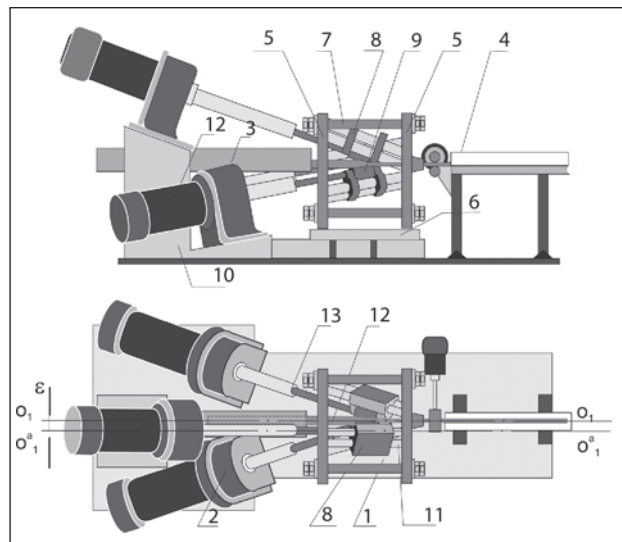


Fig. 2. Principal arrangement of «10-30» type minimill:

1 — reduction mill; 2 — roll drives; 3 — input side; 4 — output side; 5 — support plate; 6 — flat foundation; 7 — rod; 8 — cartridge; 9 — work roll; 10 — frame of main drive; 11 — guide rod; 12 — billet; 13 — spindle gear

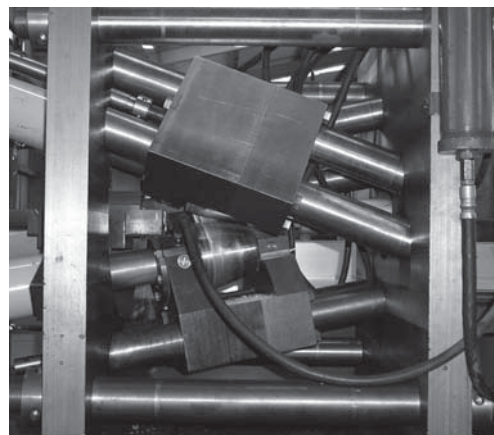


Fig. 3. Reduction mill of mini-mill of type with lateral adjustment of rolls

layers of a billet and acceleration of internal ones (Fig. 1) creates intensive macroshear motions in the deformation zone. Decrease in outer particle motion speed is caused by formation of extending flow tubes (diffusers) (Fig. 5).

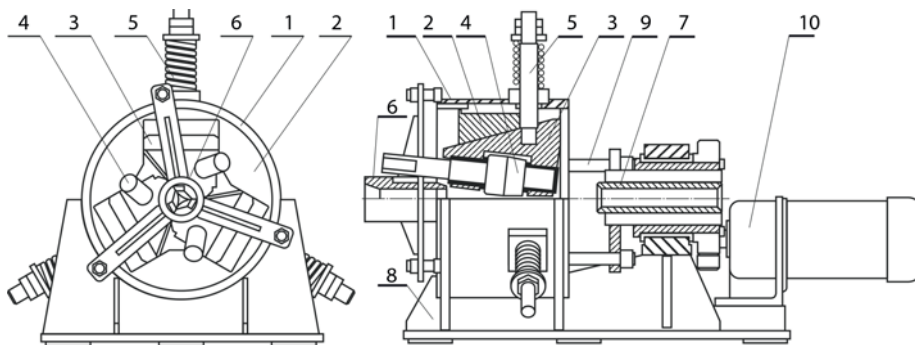


Fig. 4. Cross and longitudinal sections of «14-40» mini-mill stand:

1 — fixed external casing; 2 — mobile shoe; 3 — cartridge; 4 — work roll; 5 — spring draw bar; 6 — run-in chute; 7 — run-out chute; 8 — base plate; 9 — rod; 10 — gear motor

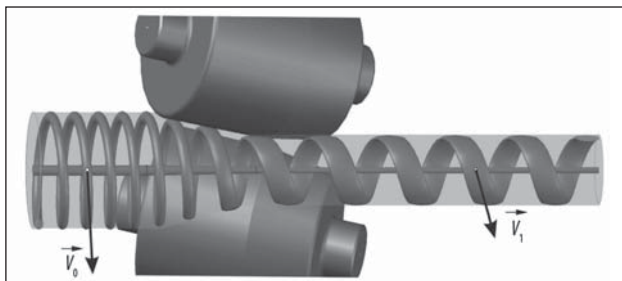


Fig. 5. Kinematic diagram of metal flow in RSR with deceleration of outer layers and formation of extending tubes of flow

A small-tonnage production of elongated VT1-0 alloy bars in submicrocrystalline (SMC) and nanocrystalline (NC) conditions has been established in the Center of Nanostructural Materials and Nanotechnologies of the Belgorod State University [6]. The technological base of the production is composed of a combination of intensive plastic deformation (IPD) in the “14-40” type radial-shear rolling mini-mill with traditional methods of lengthwise rolling and thermomechanical processing. The combination of radial-shear and lengthwise rolling shows obviously expressed synergic effect in the structure processing and increase of the metal properties [2,7]. The reached mechanical characteristics of SMC- and NC-titan correspond to the complete complex of requirements to materials for medical implants applied in the traumatology, orthopedics, and stomatology. Similar rolling mini-modules have been created in IPSM Institute of the Russian Academy of Sciences (Ufa city) and IFPM Institute of the Siberian Branch of the Russian Academy of Science (Tomsk city).

It is fundamentally important to note that as of today the radial-shear rolling is practically non-alternative method of industrial production of titanium elongated bars with SMC and NC structure.

Together with GMT Company (Germany), an automatic complex of thermomechanical processing of elongated bars has been created [8] with the process of trajectory-controlled radial-shear rolling [5]. The complex includes (Fig. 6) the following sequentially located equipment: incoming billet rack (1); pass thru induction heater (2); through-type furnace of temperature equalization (3); three-roll radial-shear rolling minimill (4); through-type furnace of temperature equalization (5); accelerated cooling facility (6), induction facility of quenched structure tempering (7); hardened rolled products rack (8). The facilities are integrated into a uniform complex with end-to-end-flow computer control

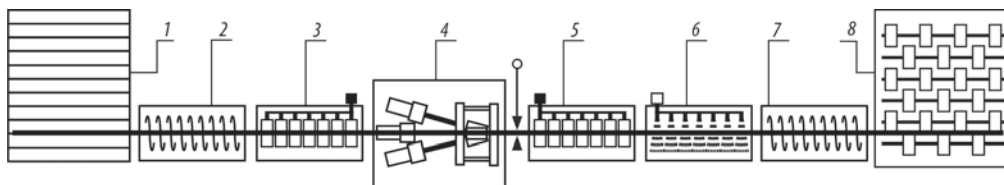


Fig. 6. Diagram of automatic complex of thermomechanical processing of elongated bars with radial-shear rolling (RSR) process: 1 — billet rack; 2 — pass thru induction heater; 3 — through-type furnace for temperature equalization; 4 — three-roll radial shear rolling mini-mill; 5 — through-type furnace for temperature equalization; 6 — accelerated cooling facility; 7 — induction facility for quenched structure tempering; 8 — rack for hardened rolled products

of the processing. The diameter of manufactured bars is 12–40 mm; length is up to 8 m. Mill products material includes alloyed constructional and laminated spring steels of 38KhM (42CrMo4) and 50S2Kh (54SiCr6) type. Deformation temperature is 550–750 °C.

The complex uses «25-45» stand similar in the construction to «10-30» mill with axial adjustment of eccentrically installed rolls.

The complex allows us to produce long-length mill products with isotropic finely-dispersed outer layer and fibered inner one. Such a condition of the structure classified as laminar naturally composite favorably affects the operation properties of the articles especially working under the torsion loads.

Ultimate strength of 2150 MPa, yield stress of 1950 MPa at relative elongation of 10 % and contraction ratio of 45 % have been obtained in the production of laminated springs of 50S2Kh (54SiCr6) steel for cars.

Modular section with innovative technology rebuild recycling of used pump rods on the basis of radial-shear rolling mini-mills of «10-30» and «14-40» types are constructed at a number machine-building enterprises. Traditional processes of repair of boring bars is mainly based on mechanical operations of screening procedure, straightening, turning, or local grinding. Thus, a significant part volume (3D) imperfections, such as, cracks, localized thinning of rod body, corrosive defects, operational fatigue fall into non-removable in principle and the rods to non-repairable ones. The rods, which have been struck by volume defects, are transferred to metal scrap. The radial-shear rolling prolongs the life cycle of similar rods, at the expense of hot plastic treatment of larger diameter rods (19 and 22 mm) to smaller diameter rods (19, 16 mm, and less). In carrying out the intensive radial-shear deformation, the surface is renovated, the majority of peripheral defects is eliminated. Removing operational stress and eliminating microdefects, the recrystallization recovers the metal properties in the volume of rod body. Rods of smaller diameter, which have the properties of the new one, are fabricated out of the produced rolled products. The rods recovered with the new process obtain the same warranty period as the new one.

The efficiency of the RSR process application in tube making is especially high in going to rather cheap continuously-casted billets. The diagram (Fig. 7) proposed in MISiS more than 40 years ago [9] is rather promising.

The deformation under the “circle-circle” diagram with free selection of diameters ensures unrestrictedly wide assortment of billets for piercing from continu-

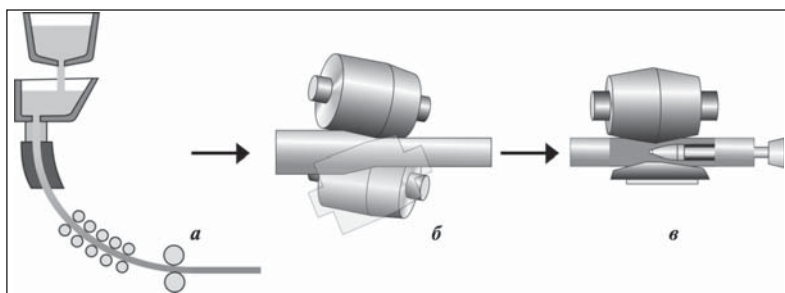


Fig. 7. Process diagram of seamless tube production out of continuously-casted billet:

a – continuous casting; *b* – radial-shear rolling; *c* – piercing

ously-casted billet of one or two diameters. For the first time the RSR integration into the process diagram of a pipe-rolling plant is realized in TPA 200 at “VTZ” OJSC [10]. The given plant incorporates two three-roll reeling stands, one of which has been updated for the RSR realization. This allows us to produce for piercing of a billet of optimum diameter in the range of 90–140 mm from continuously-casted section in diameter of 156 mm.

Moreover, radial-shear deformation with deceleration of peripheral layers and acceleration of internal ones improves qualitatively the structural state of continuously-casted metal, raises its technological ductility at the subsequent stages of processing and, first of all, in piercing. The development of initial surface defects is reduced. Maximum deviation of diameter no more than $\pm 0.5\%$ of nominal one is steadily ensured. The curvature of bars does not exceed 0.75 mm per running meter. The effect of negative features of the structural morphology in continuously-casted metal on the quality of end production and the technological production costs is completely eliminated in practice.

Successful experience of application of adapting radially-shearing deformation in continuously-casted billets before piercing has been applied in case of updating of TPA 80 («Sin TZ» OJSC [11] and TPA 200 («TMK Art rom» OJSC) [12]. The radial-shear rolling stands designed by «EZTM» OJSC in these plants are built-in directly into the process line.

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