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# Flattening of narrow and thin stainless steel strips

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## ABSTRACT

**Purpose:** The purpose of this paper is to evaluate the influence of technological parameters of flattening in the ball rolling mill on spread and geometrical properties of strips made of stainless steel of 1.4310 type and to obtain mathematical models of flattening process.

**Design/methodology/approach:** Flattening was performed in ball rolling mill in which cylindrical rollers have been replaced with balls of ~ 15mm diameter. Due to small dimensions to be measured we suggested the method of vector measurement of digital image. In order to evaluate the influence of technological parameters of flattening process, experimental planning method was used. The adoption of fractional experiment plan of $3^{5-1}$ type enabled to reduce the number of experiments to 81, despite 5 variables.

**Findings:** The results of performed tests have shown that strip spread is dependent on ball roughness, used draft, relation of wire diameter to ball diameter, back tension stress. The influence of tension stress has not been proved. Strip flatness depends on used draft. Observations have proved good quality of strip edges. No fractures have been detected, even in the case of flattening by means of big draft. Strip surface was of good quality.

**Research limitations/implications:** Test results we have obtained indicate usefulness of research method that has been used as far as determination of influence of flattening process technological parameters on spread and strip geometrical properties are concerned. It has also been proved that it is purposeful to replace cylindrical rollers with balls in rolling mills.

**Practical implications:** Flattening process mathematical models enable to assess rational procedure of flattening process parameters selection in a ball rolling mill, that determines obtaining of the required geometrical characteristics of strips. The results can be used directly when manufacturing strips for springs made of stainless steel 1.4310.

**Originality/value:** Uniform thickness throughout strip width, parallel flat surfaces, narrow dimension tolerance, good surface quality and naturally rounded side edges make it presumable that flattening method by means of ball-shaped tools is likely to become an accepted method of metal strips with required flatness manufacturing.

**Keywords: Plastic forming; Ball rolling mill; Stainless steel; Experimental planning**

MATERIALS MANUFACTURING AND PROCESSING

## 1. Introduction

The development of precision industry is responsible for constant increase of demand for narrow and thin steel strips with small dimension tolerance and functional characteristics fit for respective usage. New solutions are being sought both in the area of equipment for strip production and technologies of strip production. Selection of the best technology of narrow and thin strip production depends among other things on type of material the strip is to be made of, its final dimensions and properties, requirements concerning surface and edge quality.

An efficient method of strip manufacturing is their flattening in ball rolling mill. In this unique and prototypical machine cylindrical rollers have been replaced with balls of ~ 15mm diameter. The roller is used for flattening wires with diameter below 0,5 mm.

Proper selection technological parameters of wire flattening process determines obtaining of strips with required functional characteristics and geometrical properties. The paper presents evaluation of the influence of technological parameters of flattening process in the ball rolling mill on spread and flatness of rolled strips made of hardened stainless steel of 1.4310 type. Experimental planning method enabled to obtain flattening process mathematical models thanks to which it is possible to design and control production process in such a way to obtain strips of required dimensions, with required geometrical properties.

Stainless steel of austenitic structure, selected for tests, is very plastic when in softened state, but its strength properties are low. Their increase can be obtained thanks to cold working, for example by drawing and flattening. Wire and strips are used among other things for production of elastic and joined elements. They also serve for production of strings, medical equipment, devices for chemical and food industries [1-7].

## 2. Materials and methods

Basic material for research was hardened stainless steel wire X10CrNi18-8 (steel 1.4310). Drawing technology was selected in such a way that the wire featured high strength, the same as is required from wire used for spring production. Such selection of the material was determined by its usability (a lot of ways of application of narrow and thin strips made of this steel for production of elastic elements for precision goods industry) [1,2]. Tested material chemical composition is given in Table 1.

Table 1.
Chemical composition od steel 1.4310

| C | Mn | Si | P | S | Cr | Ni |
|---|---|---|---|---|---|---|
| 0.08 | 0.91 | 0.68 | 0.028 | 0.001 | 17.96 | 8.42 |

Flattening performed in ball rolling mill (fig.1) in which cylindrical rollers have been replaced with balls of ~ 15mm diameter. The balls are supported by driven resistance rollers. The device is used for flattening of wire with diameter below 0,5 mm [8-10].

Proper realisation of flattening process is dependent on numerous parameters, including( among other things diameter and condition of roller (ball) surface and relation d/D (where d means wire diameter and D – roller diameter), hardening condition and structure of wire to be flattened, draft, pull and counter-pull and the conditions of friction in the area of contact with rollers [11-16]. The listed above parameters may be of great influence on metal flow during plastic strain, and therefore they may influence geometrical characteristics of obtained strips. That is why it is purposeful to elaborate mathematical relations for the process of strip flattening in ball rolling mill and thus to determine quantitative relations between spread and strip shape as well as dimensions accuracy indicators, and technological process parameters. Fig.2 presents rolling unit of ball rolling mill.

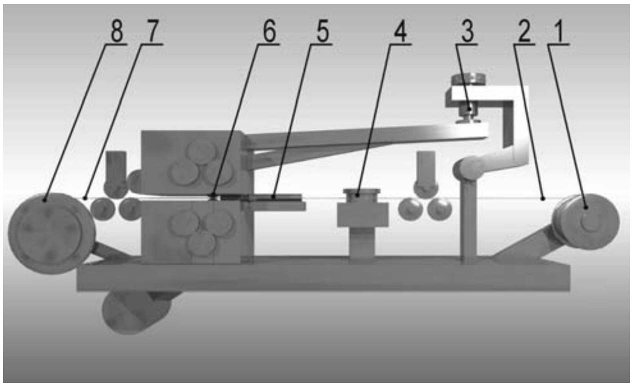

Fig. 1. Diagram of rolling mill(1-unwinder, 2- wire, 3- screw to regulate the pressure, 4-container with lubricant, 5-rolling train, 6-rolling balls, 7-strip, 8-decoiler)

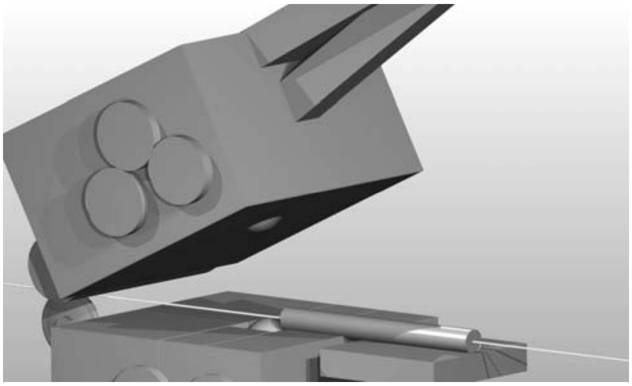

Fig. 2. Rolling unit of ball rolling mill

Application of optimization techniques enables to analyse the importance of interaction between technological parameters and product characteristics. They enable to determine mathematical relations that are the basis for design and control of manufacturing process. In the performed tests three-level planning was used [17]. The adoption of fractional experiment plan of $3^{5-1}$ type enabled to analyse the importance of interaction of five initial variables (selected process parameters) on resulting characteristics (spread coefficient $\beta$ and indicators of accuracy of strip shape and dimensions – edge camber indicator $w_w$, parallelism indicator $w_w$ , deflection from flatness indicator $w_p$. Resulting variables were: ball roughness, relation of wire diameter d to roller diameter D, relative draft, relation of front tension stress $\sigma_N$ to wire yield stress $\sigma_p$, relation of back tension stress $\sigma_N$ to wire yield stress $\sigma_p$.

Realisation of fractional experiment plan enabled to reduce the number of tests to 81. Performance of complete and full experiment would require realisation of 243 tests. For static calculations significance level $p(\alpha) < 0.05$ was used.

After 81 tests (flattening attempts), strips were measured by means of computer-aided method of vector analysis of digital image [18]. It consisted in measurement carried out on the photo, taken by means of a camera connected to the microscope, of strip cross-section metallographic specimen, and then image computer analysis with application of Corel-Draw graphics package.

Statistic calculations were made by means of Statistica programme. 4 types of models were used to evaluate the significance of interaction of respective factors in relation to obtained results:

- model with linear-square effects together with bifactor analysis
- model with main linear effects with bifactor analysis
- model with linear-square effects
- model with linear effects.

Calculations enabled to adopt optimal models for 81 performed tests.

## 3. Results

On the ground of tests and statistic calculations it was determined that mathematical optimal models of flattening process are as follows:

- initial variable - spread coefficient $\beta$

*model with linear-square effects together with bifactor analysis*:

$$\beta=-3{,}235d/D+0{,}679R_a+3{,}246(R_a)^2+1{,}295\varepsilon_h-0{,}002\sigma_{Prz}/\sigma_p-0{,}015\varepsilon_h\cdot\sigma_{Prz}/\sigma_p+0{,}944, \quad (1)$$

- initial variable - deflection from flatness indicator $w_p$

*model with linear effects:*

$$w_p=-0{,}051\varepsilon_h+0{,}04. \quad (2)$$

It results from the calculations and analysis of obtained models, that spread of wire made of 1.4310 steel is negatively influenced by the relation of wire diameter to ball diameter, which means that spread increases when wire diameter decreases. Spread is to increase with deterioration of ball surface quality and when the process is carried out with bigger relative draft. Spread is to decrease when back-tension stress increases. The model has also shown mutual interaction (negative) between relative draft and the relation of back tension stress to wire yield stress. No significant influence of tension stress to strip spread has been observed.

Deflection from flatness indicator depends only on draft, which means that increase of relative draft will result in decrease of strip flatness.

When analysing the influence of initial variables, no significance of their influence on edge camber indicators $w_w$ and parallelism $w_r$ was found for tested wire. The size of those indicators rather results from the way of flattening process realisation.

Mathematical models of flattening process, that have been obtained, are not universal, they have to be adapted separately for respective tested material and adopted level of initial variables.

Mathematical models have then been successfully verified. Performed flattening operations proved the accordance of measurement results with calculations arising from adopted models. Both, impact direction and impact strength of respective variables on spread coefficient and deflection from flatness ratio have been confirmed.

Determined indicators of shape and dimensions accuracy enabled to establish the degree to which dimensions of flattened strip cross-sections differ from strips featuring ideally parallel flat surfaces. It has been adopted that in such a case all those indicators would equal 0. It has been assumed that indicator of edge camber (expressed in %) of tested strip should not exceed 10%, indicator of parallelism should not exceed 5% and indicator of deflection from flatness should not exceed 1%. Then it is possible to assume that the strip is characterised by required surface parallelism as well as uniform thickness throughout its width, therefore - the required flatness. It has to be added that due to the fact that there are no normative regulations here, the size of the indicators was adopted conventionally. Performed measurements proved that all tested strips feature edge camber indicator smaller than 10%. Majority of strips featured parallelism indicator smaller than 5%. 60% of all tested strips featured indicator of deflection from flatness smaller than 1%.

Measurement proved that ball rolling mill enables flattening of narrow and thin strip characterised by uniform thickness throughout their width and required parallelism of flat surfaces. If the same range of flatness is to be obtained on flat rollers, it requires proper preparation of the rollers and their frequent recovery (polishing). Those operations make production more complicated and increase its costs. As far as ball rolling mill is concerned, the tool here are bearing balls, that are produced on a large scale. Due to extremely low cost of ball purchase their frequent replacement is not a problem, which enables strip flattening with narrow dimension tolerance. Low price of balls influences economical indexes of strip production process.

Observation of metallographic specimen under microscope proved that edge quality was correct for the majority of strips. No fractures were detected, even when flattening of strips with large draft.

Visual inspection shown that strips feature high quality of surface, that is sufficient even for medical purposes. No cracks or scratches that could impair the operation of elastic elements have been detected.

In addition, roughness measurement was made on profile measurement gauge MITUTOYO SJ-20. It was found that strips flattened with balls that featured roughness of $R_a$ = 0,01 μm have roughness of 0,1÷0,2 μm. Strips that were flattened by means of balls with the worst surface quality ($R_a$ = 25 μm), feature roughness of $R_a$ = 0,23÷0,3 μm.

## 4. Conclusions

The process used to manufacture narrow and thin strips, which are characterised by parallelism of flat surfaces, high requirements concerning dimensional tolerances and appropriate quality of edges is flattening, which was till now realised with flat rollers. The new possibility of flattening appeared with ball rolling machine. In this device working element is in the form of ball-shaped tools with 15 mm diameter, placed on two driven supporting rolls. The results of research indicate that ball roller is a device that allows obtaining narrow and thin steel strips, characterised by uniform thickness over the width, high quality of surface and softly rounded side edges.

The use of computer-aided methodology of image analysis allowed precise determination of geometric features of flattened strips. The time of measurements with a vectorial measurements is considerably shorter and precision of their workmanship is incomparably better than measurements with classical methods (slide caliper, micrometer, toolroom microscope). The accuracy of measurement is determined by finishing of the used digital camera and its resolution capacity. The use of popular software allows realisation of measurements on any computer. This innovative measuring method can be used in many other applications.

An analysis of statistic calculations of fractional experiment of type $3^{5-1}$ enabled to prove significance degree of influence of initial variables on spread coefficient and the indicators of strips shape and dimensions accuracy. Obtained results made it possible to establish mathematical models of flattening. Static calculations showed that draft, ratio of wire diameter to the diameter of balls, roughness of balls and ratio of back tension to yield stress have significant influence on spread coefficient. Flatness of all examined strips is dependent on used drafts.

Uniformity of thickness over strip width, parallelism of flat surfaces, small dimensional tolerance, high surface quality and naturally rounded side edges allow to assume that flattening method with the use of round tool will become an sass, which are used among other things to make elastic elements and elements for medicine [19,20].

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