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STUDY OF THE MECHANICAL PROPERTIES OF STRIPS OBTAINED IN TRC LINE

Twin Roll Casting technology belongs to modern, integrated method of processing aluminum and its alloys. This method includes preparation of liquid metal and its continuous casting between the rotating cylindrical crystallizers, optional homogenizing treatment, cold rolling and optional interoperation or final heat treatment. Final products of TRC method are strips with a thickness from few to several millimeters, which can be directly subjected to cold rolling process to afford a sheet. Properties of final product are limited by the material's condition, its chemical composition and also selected path of its processing technology. The paper presents research results of chemical composition and mechanical properties of strips obtained in Twin Roll Casting processing line.

Technologia Twin Roll Casting należy do nowoczesnych, zintegrowanych metod przetwórstwa aluminium i jego stopów. Obejmuje ona przygotowanie ciekłego metalu i jego ciągłe odlewanie między obracające się cylindryczne krystalizatory, opcjonalną homogenizację materiału, walcowanie na zimno i opcjonalną międzyoperacyjną lub końcową obróbkę cieplną. Produktem finalnym metody TRC są taśmy o grubości od kilku do kilkunastu milimetrów, które następnie mogą być poddane bezpośredniemu procesowi walcowania na zimno w wyniku czego otrzymuje się blachy. Zespół własności finalnych danego wyrobu limitowany jest przez stan i skład chemiczny materiału oraz poprzez wybór ścieżki technologicznej jego przetwarzania. W pracy przedstawiono wyniki badań składu chemicznego oraz własności mechanicznych taśm z linii Twin Roll Casting otrzymywanych przy zastosowaniu różnych parametrów procesowych.

Keywords: aluminum, twin roll casting, hardness, anisotropy, segregation

1. Introduction

In the recent years has occurred a systematic increase in the production of aluminum (about 4% per year), while maintaining wider and wider substitution of alternative products made of aluminum and its alloys for its various industries. One of the first step of converting aluminum, obtained in metallurgical processes, is its casting process to the form of sows, blocks, strips, rods and so on. Commonly used lines for semi-continuous casting and hot rolling process in processing aluminum alloy for plastic working are characterized by high efficiency. For this reason, frequently changes of manufacturing profile or assortment cause large organizational and technical difficulties and the risk of generate a lot of waste. Considered conventional technology is energy-consuming and requires expanded manufacturing infrastructure, which is the reason of decreasing of competition among manufacturers caused by investment and financial reasons. Many companies while searching for new ready markets is begin to focus on the manufacturing of specialty and dedicated materials. Such companies focus their attention on smaller, more flexible lines which allow to quick changes of manufacturing profile. Response for the depicted demand is an alternative manufacturing method which uses continuous casting of aluminum and its alloys between the rotating cylindrical crystallizers known as the Twin Roll Casting. Due to the clear shortening of technological cycle, TRC method belongs to the group called "near net shape manufacturing." Applying this modern method allows for the elimination of hot rolling process from the manufacturing process. This results in significantly reduces costs of production and return on investment, by reducing the cost of production infrastructure by eliminating hot mill (tens of million zlotys) and generates less waste because of eliminates waste machining, which is required with conventional ingot, and also allow to quick changes of product range. Thus, manufacturers are able to produce larger quantities at a similar effort and energy costs, while increasing the production range and ready markets. In this method, recycled aluminum materials may be used successfully, which additionally reduces of manufacturing costs. Companies benefiting from sheets and strips based on aluminum for the manufacturing of final products such as packages, heat exchangers, architectural, electrical elements and other, get cheaper semi-finished product by reducing the price of final product and becoming more competitive [1-4].

Casting by using Twin Roll Casting method also provides attractive mechanical properties and material structure, which can be obtain by using the appropriate technological path during

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processing material for sheets. In case of manufacturing some products can be obtain essential advantageous set of material's utility properties (combination of high strength with adequate formability and increased recrystallization resistance). This method is therefore good and competitive alternative compared to classic casting method and manufacturing flat products of aluminum and its alloys [5-6].

2. Materials and experimental work

The first step of testing procedure included melting of aluminum (with chemical composition correspond to the EN-AW 1370 grade) and heated to a temperature of 720°C (in melting-casting furnace). The next step was made additions of appropriate metallurgical mortar of AlFe80 (for casting 8XXX aluminum alloys). Particular alloys were well stirred and then left in a furnace for 20 minutes in order to homogenize chemical composition. Then the casting process were started. Metal, heated to temperature of 720°C were transmitted on rolls-crystallizers with the aid of a specially prepared deluge system, which was additionally heated to a temperature of 800°C in order to avoid the possibility of solidification of metal before an entry between rolls. Obtained materials in the strip form are characterized with a thickness of 9 mm and a width of 90 mm. Then the samples were fetched to researches. Figure 1 shows the continuous casting system of the strip manufacturing.

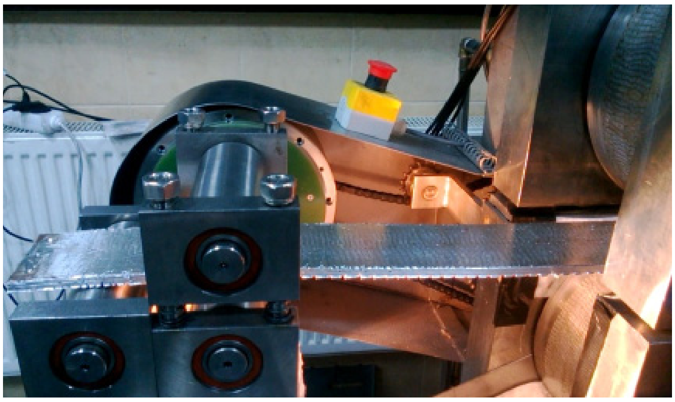

Fig. 1. View on continuous casting line during a stable work-manufacturing of strips in straight section

At first, the chemical composition of obtained strips were tested. Researches were conducted on three different cast - a base material aluminum in grade EN-AW 1370 and two aluminum alloys with content of iron respectively 0.4% (with chemical composition correspond to the EN-AW 8176 grade) and 0.73% (corresponding with EN-AW 8079). Casting speed of tested strips was 0.4 m/min and coolant flow rate was 22 l/min. Studies were conducted in order to verification, whether in studied process occurs the phenomenon of segregation of alloying elements, which is known from different continuous and semi-continuous casting processes. Chemical composition measurement was achieved by 10 tests on each 0.9 mm on the strips thickness.

Mechanical properties test were conducted for aluminum strip in grade EN-AW 1370, aluminum alloy with iron content of 0.4% (corresponding with EN-AW 8176) and 0.73% of iron (corresponding with EN-AW 8079). Strips were casted with different casting speed (0.3-0.7 m/min) and coolant flow rate (3-22 l/min). Obtained strips were conducted to research in order to determinate values such as: tensile strength, yield stress, total elongation and elongation. These properties was determined by testing samples taken at a different angles relative to casting direction (0°, 22.5°, 45°, 67.5° and 90°), the aim was to determine possibility of occurrence of the mechanical anisotropy of tested strips. Measurement base in this test was 40 mm, which results from dimensions of obtained strip.

Hardness tests were conducted on thickness of obtained strips in order to verify some properties changes, which could be due to variable concentration of alloy addition and variable structural (grain size) on casting thickness. There have been also studied the average hardness of the material as a function of the casting speed, coolant flow rate and chemical composition. Measurements on the thickness of the cast was measured every 2 mm (result is the average of 3 measurements). The average hardness is, however, the average of all the 15 measurements performed on each sample.

3. Results and discussion

On the Fig. 2-4. are presented a research results of chemical composition of obtained strip.

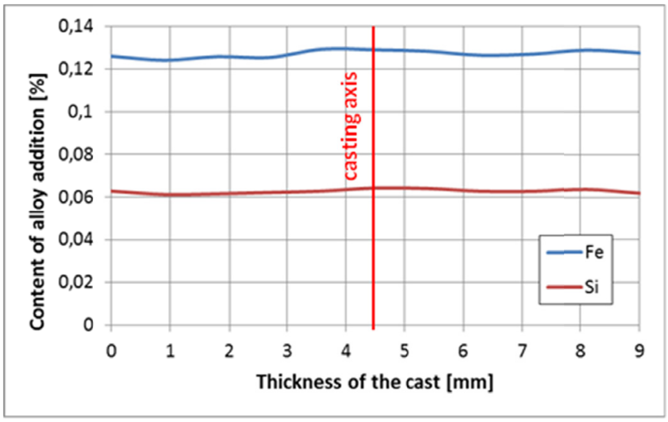

Fig. 2. The results of the measurement of the main additives for aluminum grade EN AW-1370

The results suggest that during casting process of strips in TRC technology can occur segregation of alloy addition to the form of iron mainly in the axis of obtained cast. This correlates with the observation known from the literature discussed briefly in paper [7]. Measurement results show the presence of iron in the vicinity of the casting axis in amount of about 7% higher than in the other parts of alloy with iron amounts of 0.4%. For alloy with amount of 0.73% iron this difference reaches up even to 8%. Slightly higher level of discussed element was

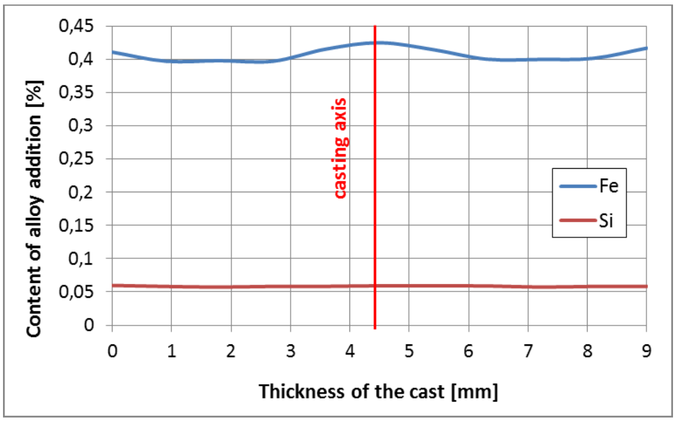

Fig. 3. The results of measurements of added Fe and Si for aluminum containing 0.4% iron

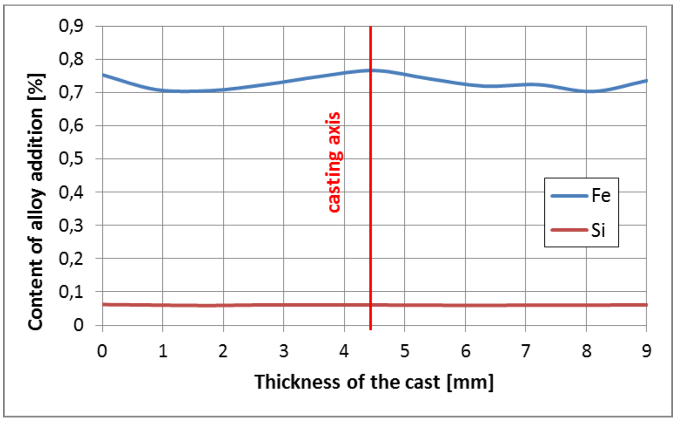

Fig. 4. The results of measurements of added Fe and Si for aluminum containing 0.73% iron

also observed at the edges of studied strips. In the case of pure aluminum there is not significant differences in the content of both iron and silicon in the thickness of the cast. Evaluation of material properties as results of tensile test was accomplished for each of the casting strips, in figures 5-14 are presented received strength characteristics.

Based on the analysis of mechanical properties shown in the Fig. 5-14 it can be seen that changes of process parameters such as casting speed or coolant flow rate does not affect significantly on strength and plastic properties of particular strips. Observed properties correspond to properties of pure aluminum. Presence of iron in an amount of 0.4% causes an increase of proof stress of 8.1% and increase of tensile strength of 18.1% compared to pure aluminum. This is due to simultaneously a decrease of plastic properties represented by an extension of 35-37%. Increasing

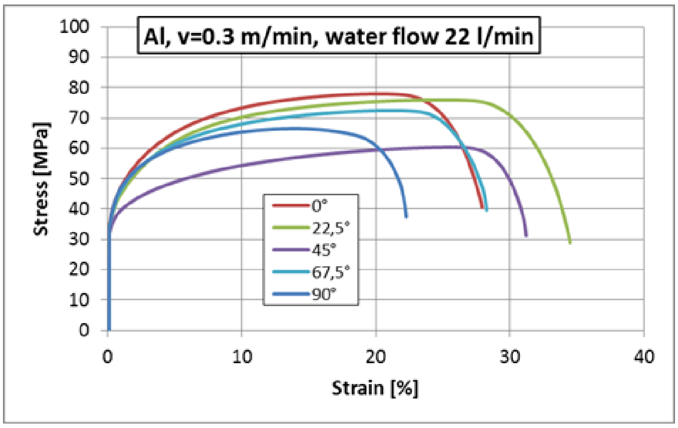

Fig. 5. Stress-strain curve for aluminum strip, casting speed 0.3 m/min, coolant flow rate 22 l/min

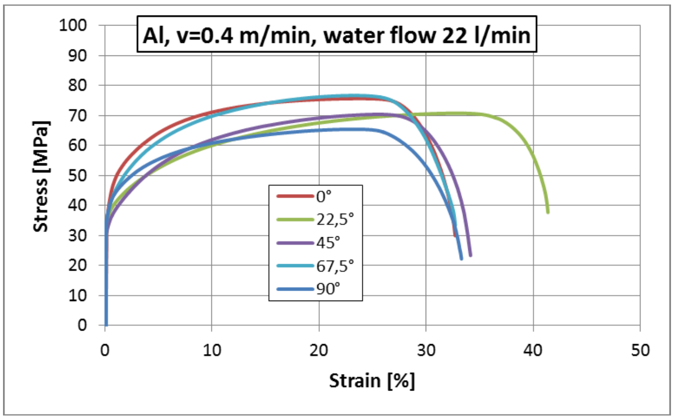

Fig. 6. Stress-strain curve for aluminum strip, casting speed 0.4 m/min, coolant flow rate 22 l/min

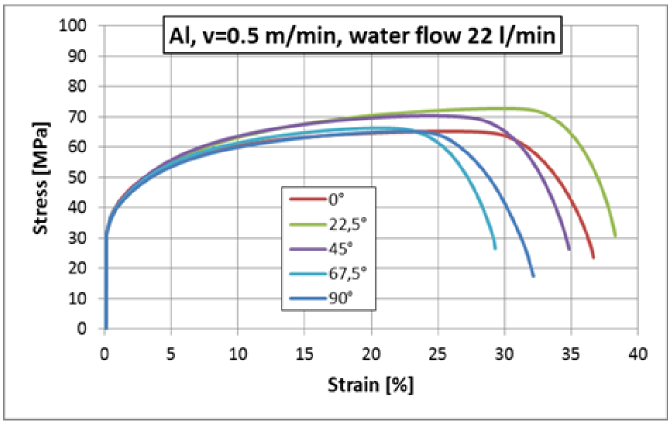

Fig. 7. Stress-strain curve for aluminum strip, casting speed 0.5 m/min, coolant flow rate 22 l/min

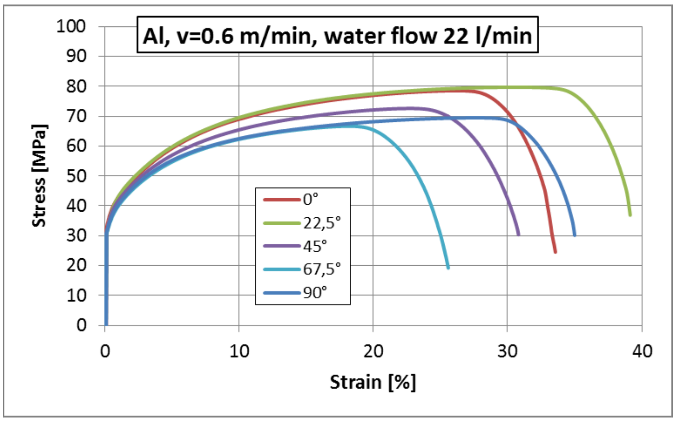

Fig. 8. Stress-strain curve for aluminum strip, casting speed 0.6 m/min, coolant flow rate 22 l/min

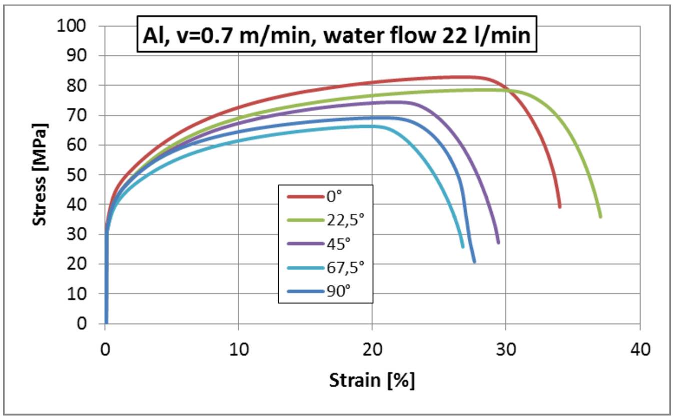

Fig. 9. Stress-strain curve for aluminum strip, casting speed 0.7 m/min, coolant flow rate 22 l/min

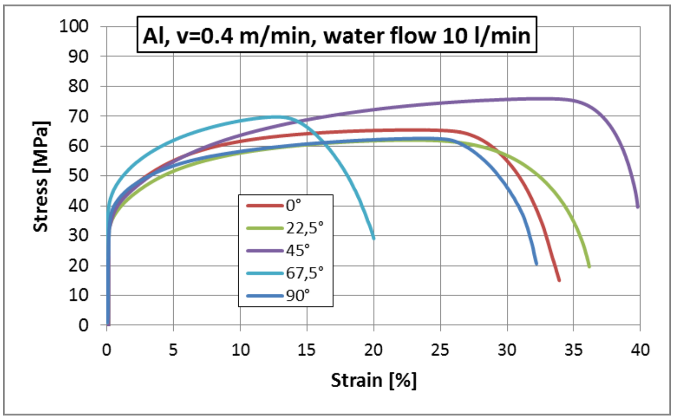

Fig. 10. Stress-strain curve for aluminum strip, casting speed 0.4 m/min, coolant flow rate 10 l/min

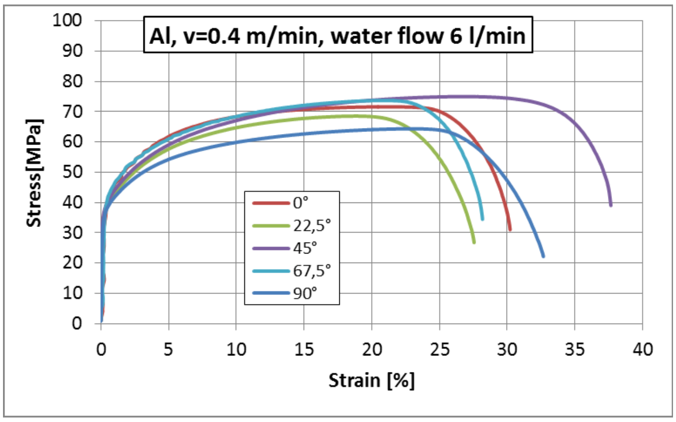

Fig. 11. Stress-strain curve for aluminum strip, casting speed 0.4 m/min, coolant flow rate 6 l/min

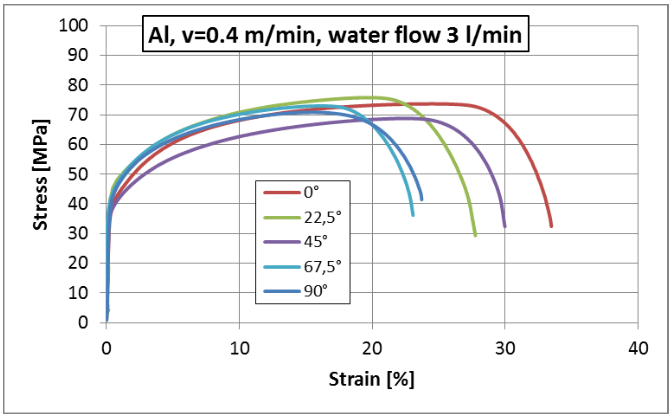

Fig. 12. Stress-strain curve for aluminum strip, casting speed 0.4 m/min, coolant flow rate 3 l/min

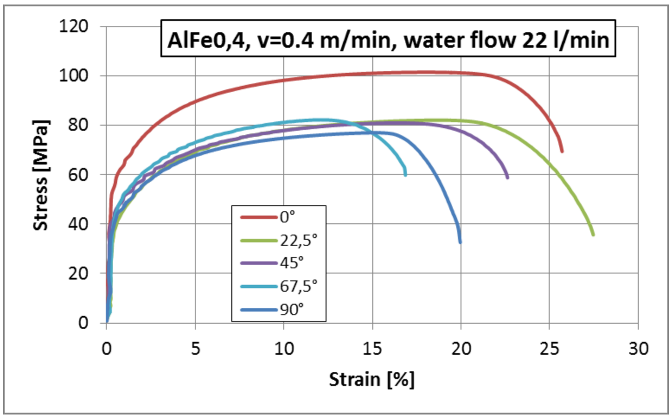

Fig. 13. Stress-strain curve for aluminum strip with 0.4% content of iron, casting speed 0.4 m/min, coolant flow rate 22 l/min

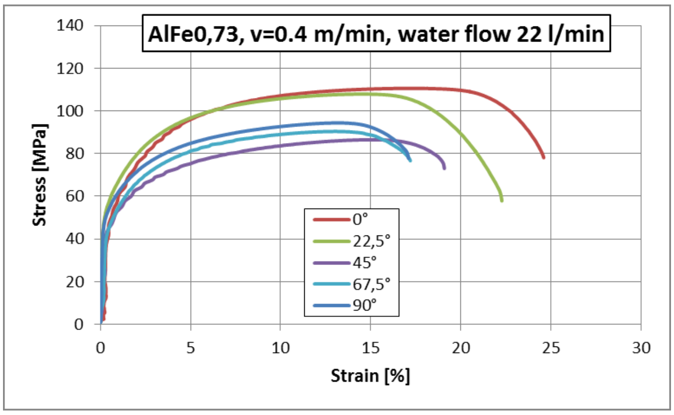

Fig. 14. Stress-strain curve for aluminum strip with 0.73% content of iron, casting speed 0.4 m/min, coolant flow rate 22 l/min

the amount of iron to 0.73% causes an increase of proof stress of 19.2% and increase of tensile strength of 18.1% compared to pure aluminum. It is also due to a decrease of plastic properties represented by elongation of 42%. It is caused probably due to the thermomechanical strengthening, which is often associated with formation of nonequilibrium aluminum-iron phase or aluminum-iron-silicon phase in tested alloys.

Based on the shown stress-strain curves for obtained cast it can be noted that the direction of conducted research has essentially meaning and results in a change of properties of studied materials. In order to better illustrate the scale of the observed phenomena, mechanical properties as a function of research direction (represented by an angle relative to the direction of casting) are shown in the Fig. 15-24.

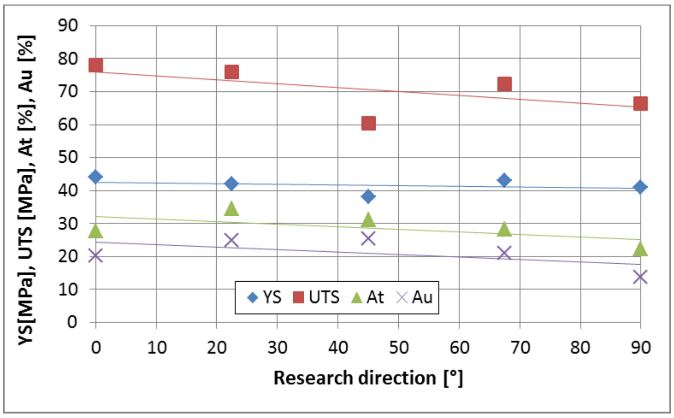

Fig. 15. Values of mechanical properties as a function of the research direction for aluminum, casting speed 0.3 m/min, coolant flow rate 22 l/min

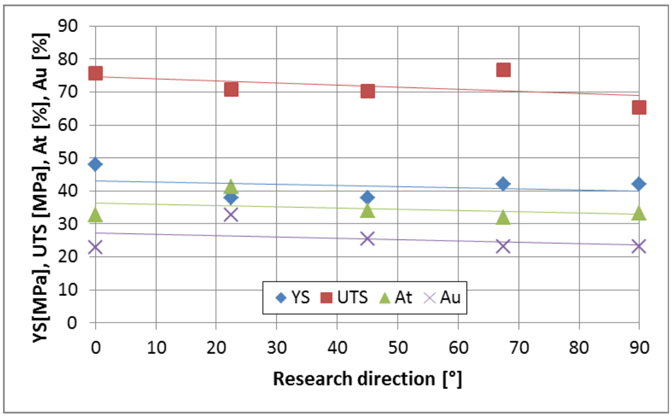

Fig. 16. Values of mechanical properties as a function of the research direction for aluminum, casting speed 0.4 m/min, coolant flow rate 22 l/min

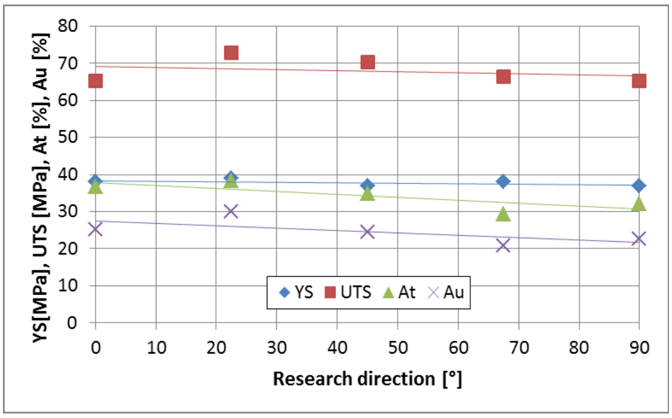

Fig. 17. Values of mechanical properties as a function of the research direction for aluminum, casting speed 0.5 m/min, coolant flow rate 22 l/min

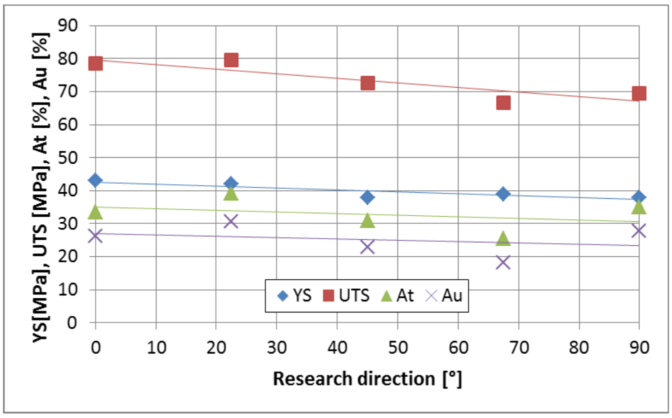

Fig. 18. Values of mechanical properties as a function of the research direction for aluminum, casting speed 0.6 m/min, coolant flow rate 22 l/min

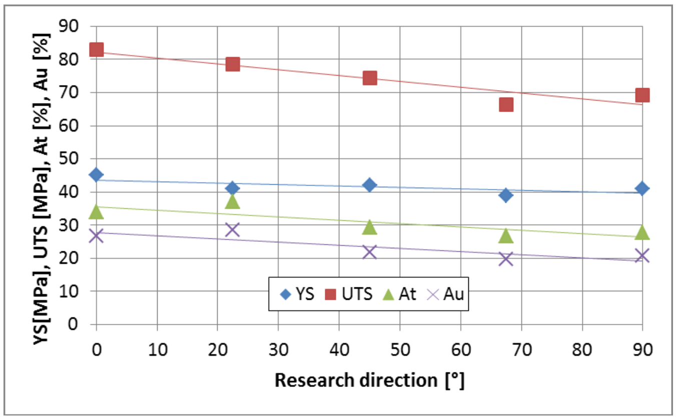

Fig. 19. Values of mechanical properties as a function of the research direction for aluminum, casting speed 0.6 m/min, coolant flow rate 22 l/min

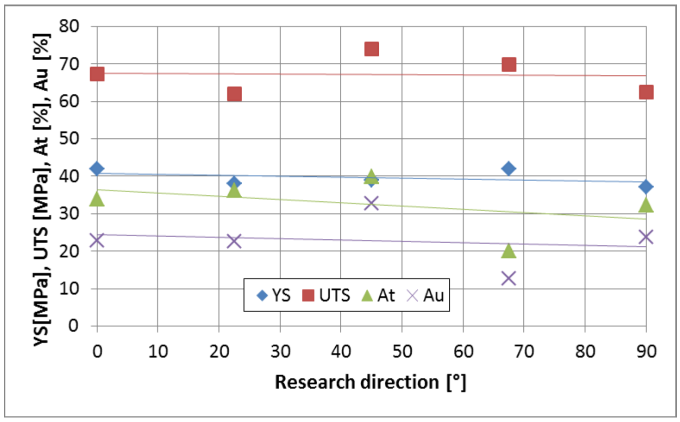

Fig. 20. Values of mechanical properties as a function of the research direction for aluminum, casting speed 0.4 m/min, coolant flow rate 10 l/min

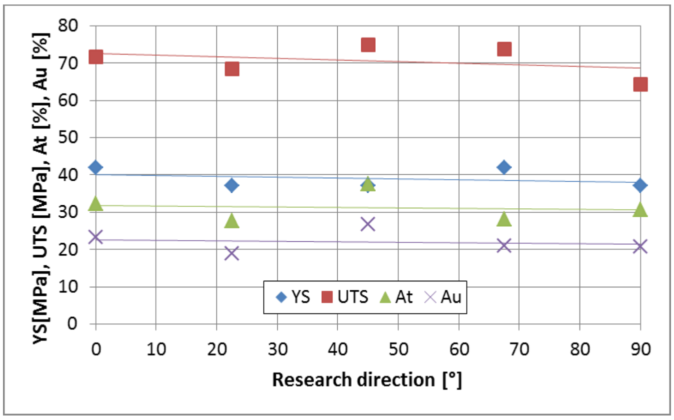

Fig. 21. Values of mechanical properties as a function of the research direction for aluminum, casting speed 0.4 m/min, coolant flow rate 6 l/min

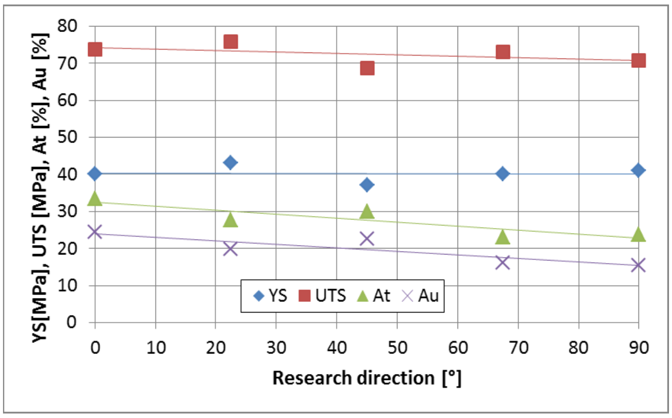

Fig. 22. Values of mechanical properties as a function of the research direction for aluminum, casting speed 0.4 m/min, coolant flow rate 3 l/min

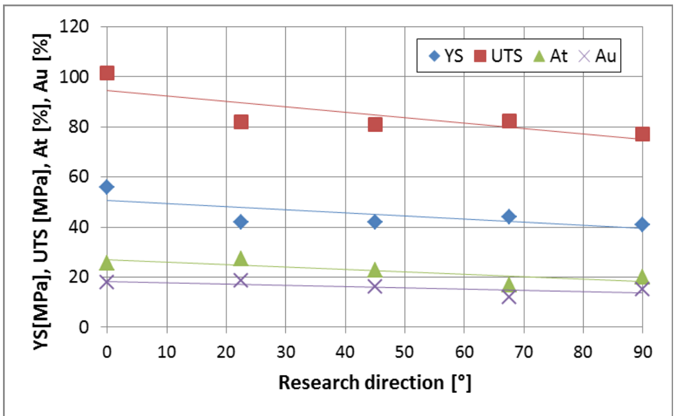

Fig. 23. Values of mechanical pr3operties as a function of the research direction for aluminum with 0.4% content of iron, casting speed 0.4 m/min, coolant flow rate 22 l/min

Based on the research results depicted for different casting speed it can be noted, that all the properties decrease with increasing an angle which the sample were taken. Observed properties are strongly depend of the research direction, it is a result of the structure, which is characteristic for TRC technology. In mate-

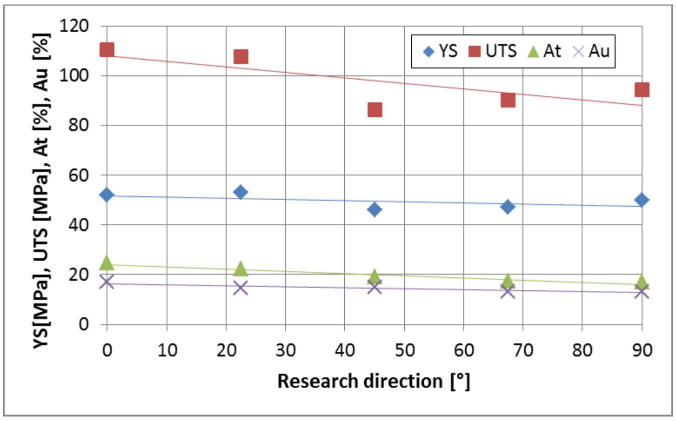

Fig. 24. Values of mechanical properties as a function of the research direction for aluminum with 0.73% content of iron, casting speed 0.4 m/min, coolant flow rate 22 l/min

rial occurs an initiation processes, which lead to the destruction mainly at the grain boundaries – this is the reason that the lowest properties of YS, UTS, At are observed in the samples which were taken at 90° relative to the casting direction, participation of the grain boundaries amount is the greatest. Similar observations have been described in paper [8].

Similar trend was observed for the samples made of different materials with different values of coolant flow rate. For variable parameters of coolant flow rate can be observed smaller differences in mechanical properties and comparable values of plastic properties – UTS ≈ 12%, YS ≈ 11.5%, At ≈ 33% and Au ≈ 37% (assuming the highest and lowest measured values).

Analyzing the results for the aluminum-iron alloys it can be also observed noticeable decrease of mechanical properties with a change of the research direction. The iron content of 0.4% results in difference of these properties as a function of the research direction at UTS ≈ 24.5% , YS ≈ 27%, At ≈ 39% and for the iron amount of 0.74% this differences are lower: UTS ≈ 13%, YS ≈ 22.5%, At ≈ 30.5%.

In Fig. 25-27 are illustrated research results of hardness penetration pattern of studied strips as a function of the casting speed, coolant flow rate and chemical composition.

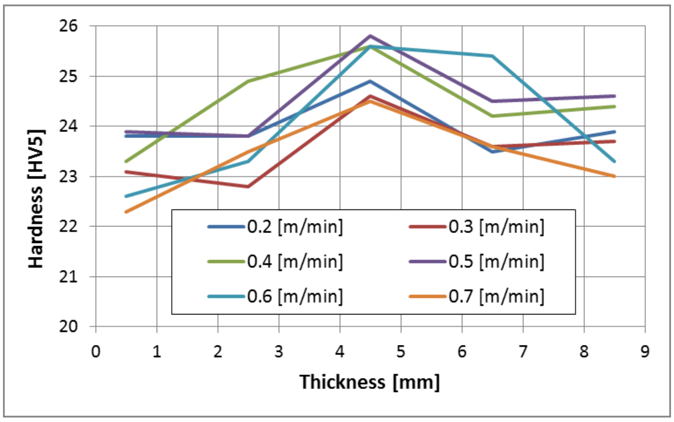

Fig. 25. Hardness penetration pattern on cast thickness as a function of casting speed

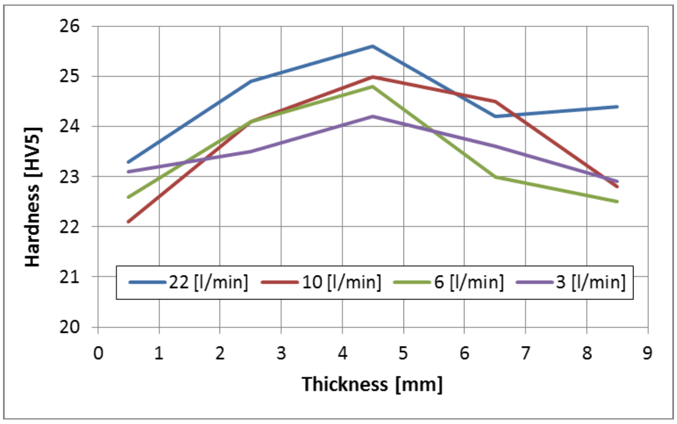

Fig. 26. Hardness penetration pattern on cast thickness as a function of coolant flow rate

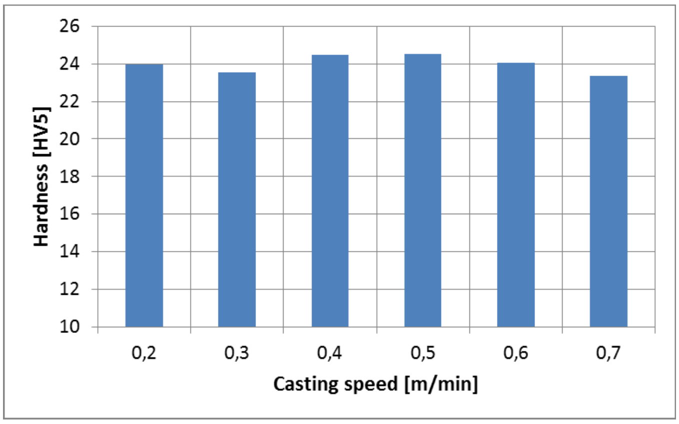

Fig. 28. Average hardness of strips from TRC line as a function of coolant flow rate

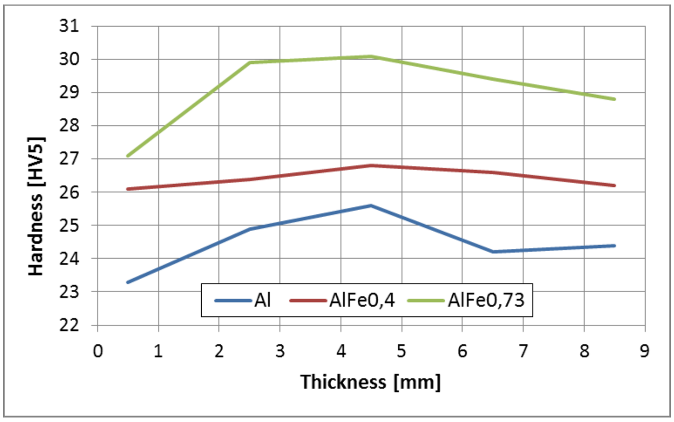

Fig. 27. Hardness penetration pattern on cast thickness as a function of chemical composition

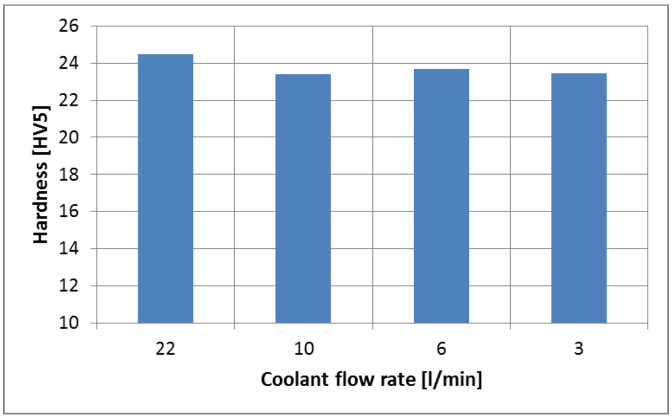

Fig. 29. Average hardness of strips from TRC line as a function of chemical composition

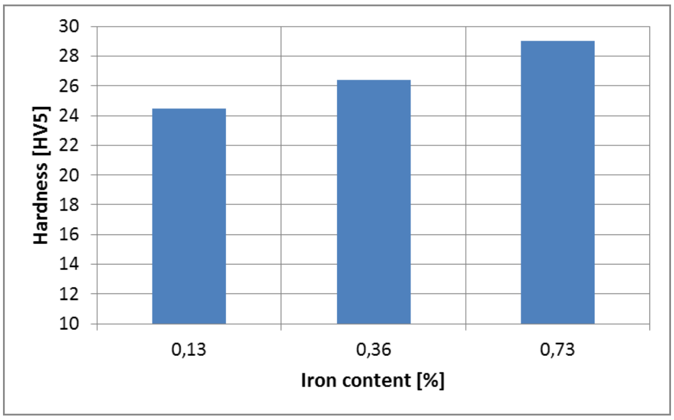

Fig. 30. Average hardness of strips from TRC line as a function of chemical composition

Presented results of hardness penetration pattern clearly show that hardness of studied cast is variable on thickness of the cast. Hardness values is higher in the central part of the strip than at the edges. There is a possibility that it may be due to the phenomenon of segregation of alloy addition in the axis of the cast, which was also noted for the study of the chemical composition and provides evidence indicating the possibility of existence of normal anisotropy of mechanical properties.

Matching of average hardness of materials (shown in Fig. 28-30) clearly shows that hardness does not depend on either the casting speed or coolant flow rate and it is approximately reaches a value 24 HV5. A noticeable difference can be observed while introducing an alloy addition in the form of iron to base material, which leads to an increase of hardness about approximately 2 HV5 with a content of 0.4% of iron and about 4.6 HV5 with a content of 0.73% of iron. These results are consistent with the papers [9-10]. Hardness tests are correlate well with the stress-strain curves, where also did not notice significant differences in the mechanical properties tested depending on casting parameters. However, the differences were observed for the strips with different iron content as alloy addition.

4. Conclusions

The paper presents an analysis of mechanical properties of the strips obtained in TRC technology with different process parameters, such as casting speed or coolant flow rate. Researches were conducted also for different aluminum alloys, both the series of 1XXX and 8XXX, differing mainly with the content of iron. Study of the chemical composition shows that for strips obtained in TRC technology may occur segregation of the alloy addition in the form of iron, mainly in the casting axis. This phenomena concerns mainly 8XXX series of aluminum alloy. Based on the analysis of mechanical properties it can be seen that the change of process parameters such as casting speed or coolant flow rate does not affect significantly on the strength and plastic properties of particular strips. Observed properties are strongly dependent of the research direction, which is the result of the structure typical for TRC technology. Results of hardness penetration pattern clearly show that hardness is higher on the central part of strip than at the edges. There is a possibility that it may be due to the phenomenon of segregation of alloy addition in the casting axis, which was also noted in the chemical composition tests.

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