A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 53 2008 Issue 2

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ANALYSIS OF EXPERIMENTAL RESULTS OBTAINED BY ESR AND VAR PROCESS FOR SPECIAL STEELS

ANALIZA WYNIKÓW DOŚWIADCZALNYCH UZYSKANYCH W PROCESACH ESR I VAR DLA STALI SPECJALNYCH

The paper presents the results regarding quality of special steels for aero industry, obtained by two different processes: Electro Slag Remelting (ESR) and Vacuum Arc Remelting (VAR) on pilot experiments.

The main object of these trials was obtaining super clean steels (oxygen <20 ppm, hydrogen <1 ppm, nitrogen <20 ppm, sulphur <50 ppm, phosphorus <100 ppm) and a controlled solidificated structure of steel semis. The experiments took off the benefits of vacuum arc remelting process, for decreasing gaseous content of steels versus electro slag remelting process which can improve the decreasing of sulphur content of steel. In order to analyse the influence of a double vacuum process VIM – VAR (Vacuum Induction Melting and Vacuum Arc Remelting) on quality of steel, some trials were also performed.

Keywords: ESR, VAR, VIM, Special steels, Capability

Artykuł przedstawia wyniki dotyczące jakości stali specjalnych stosowanych w przemyśle lotniczym, uzyskane z dwóch różnych procesów: elektrożużlowego przetapiania stali i przetapiania w próżni na podstawie badań pilotażowych.

Głównym przedmiotem badań było uzyskanie super czystych stali (tlen <20 ppm, wodór <1 ppm, azot <20 ppm, siarka <50 ppm, fosfor <100 ppm) i kontrola struktury bliźniaków w krzepnącej stali. W doświadczeniach wykorzystano korzyści płynące z odgazowania stali w procesie próżniowym, naprzeciw możliwościom elektrożużlowego przetapiania, które poprawia odsiarczanie stali. Wykonane zostało również kilka prób, aby przeanalizować wpływ procesu VIM – VAR na jakość stali.

1. Introduction

In order to improve the performances of our units in producing special steels designated to aerospace industry, our research work was focused on the evaluation of ESR, VAR and VIM plants capabilities. The trials were performed in two VIM plants, one ESR plants and two VAR plants. The features of these plants are presented in Table 1, 2 and 3.

TABLE 1

Features of VIM plants

Features	Plant No.1	Plant No.2
Capacity, kg	50	2500
Vacuum, Torr	$10^{-3} - 10^{-5}$	$10^{-2} - 10^{-3}$
Power, kW	10	60

TABLE 2

Features of ESR plant

Features	No.1 Plant
Crystallizer, mm	150
Ingot weight, kg	150
Transformer power, kVA	800
Secondary tension, V	28–63 (6 stages)
Intensity, A	max 2300
Frequency, Hz	50

TABLE 3

Features of VAR plants

Features	Plant No.1 – L200	Plant No.2 – L300
Crystallizer, mm	80, 110, 150	204, 255, 306
Vacuum, Torr	10^{-3}	10^{-3}
Transformer power, kVA	54	600
Suply tension: V	380	3x380
Work tension: V	10–20	25–27
Intensity, A	200–2500	0–1000

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2. Technological routes and steel grade

The technological routes which were used for trials and performed steel grades are presented in Table 4.

TABLE 4

Technological routes and steel grades

		No.1 Route ESR	No.2 Route VAR	No.3 Route VM-VAR
Primary melting		EAF (IM)	EAF(IM)	VIM
Primary refining		ESR	VAR	VIM
Secondary refining		–	–	VAR
Steel grades %	carbon steel	4.8	7.6	0.0
	low alloy steel	88.9	89.3	45.5
	high alloy steel	6.3	3.1	54.5

3. Performances on sulphur and phosphorus in steel

The minimum, maximum and average values of sulphur and phosphorus obtained on the three technological routes are shown in Fig. 1 and Fig. 2.

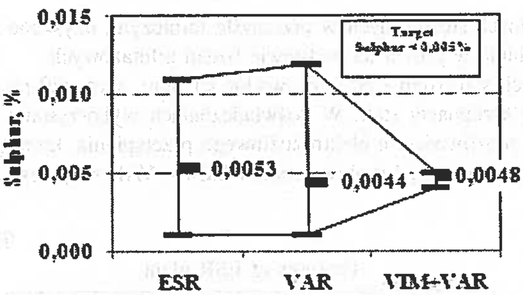

Fig. 1. Performed sulphur vs process

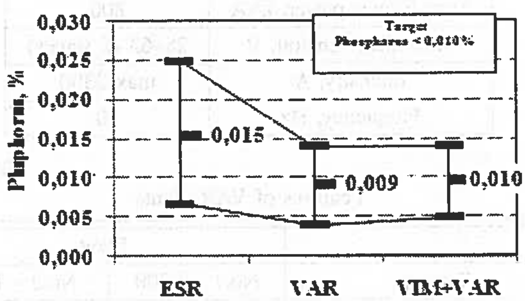

Fig. 2. Performed phosphorus vs process

As it can be seen the best performance for sulphur target was obtained by VIM-VAR route. Although the steel produced by all technological routes had a sulphur content below our target (maximum 0.005%), only the VIM – VAR route had the lowest variation – about 0.001%.

In case of phosphorus, ESR route cannot assure the achievement of the target (maximum 0.010%), but both routes with VAR can achieve this target.

Another evaluation was made for the target sulphur + phosphorus. In this case, the target was maximum 0.0150%. The result of this analisys is presented in Fig. 3. As it can be seen this target was achieved both by VAR and by VIM-VAR routes, but the ESR route cannot achieve this target.

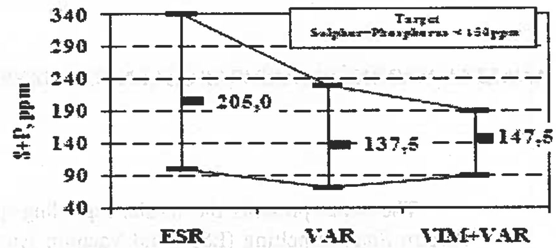

Fig. 3. Performed sulphur+phosphorus vs process

4. Performances on oxygen, nitrogen and hydrogen in steel

The targets for these three potential dangerous components were: maximum 20 ppm for oxygen and nitrogen, and maximum 1 ppm for hydrogen. The analysis for O_2, N_2 and H_2 are presented in Fig. 4–7.

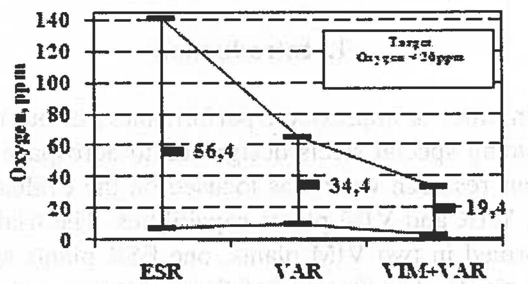

Fig. 4. Performed oxygen vs process

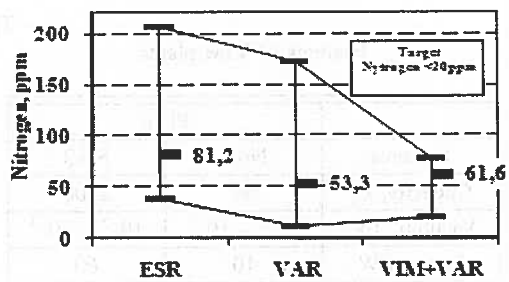

Fig. 5. Performed nitrogen vs process

As it can be seen from Fig. 4, the target of maximum 20 ppm for oxygen was achieved by VIM-VAR route only. The target of maximum 20 ppm for nitrogen could not be achieved by any technological routes (Fig. 5); anyway, the target of 20 ppm nitrogen was too ambitious in case of allied grades and the performances for nitrogen also depends of steel grade (solubility of nitrogen in liquid and solid state). From this viewpoint, a evaluation was made for 35NCD16 steel grade (Fig. 6). As it can be seen VAR process can achieve a target of nitrogen with about 30 ppm below ESR process nitrogen.

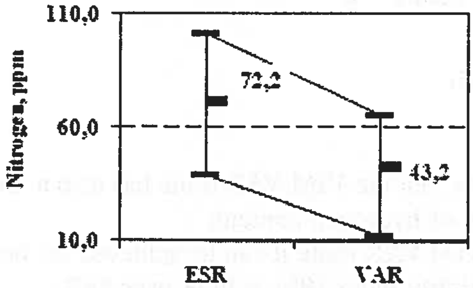

Fig. 6. Performed nitrogen vs process 35NCD16 grade

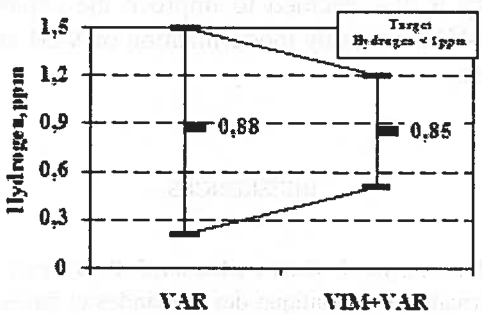

Fig. 7. Performed hydrogen vs process 35NCD16 grade

The target of maximum 1 ppm hydrogen was obtained in both vacuum routes, but the VIM-VAR route has also a lower variation of hydrogen content (Fig. 7).

Another evaluation was made for the target oxygen + nitrogen. In this case the target was maximum 40 ppm. The result of this analysis is presented in Fig. 8. As it can be seen, this target could not be achieved by any technological routes (nitrogen and its behaviour in allied grades is also responsible) but the VIM-VAR route has a lower level and a lower variation for the sum of oxygen and nitrogen.

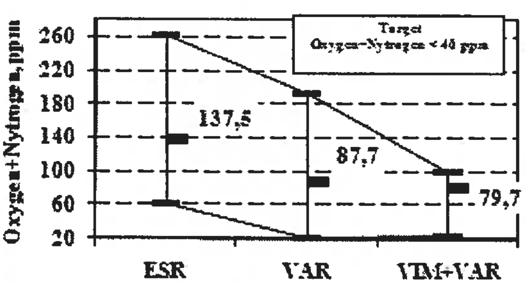

Fig. 8. Performed oxygen+nitrogen vs process 35NCD16 grade

5. Global performance

We have also tried to define a global target for these technological routes. Thus our target for evaluation of technological routes was defined by maximum 190 ppm (the sum of S, P, O_2 and N_2). The result of this analysis is presented in Fig. 9. As it can be seen, this global target could not be achieved by any technological routes (nitrogen is responsible also), but the lowest variation was once again obtained by VIM-VAR route.

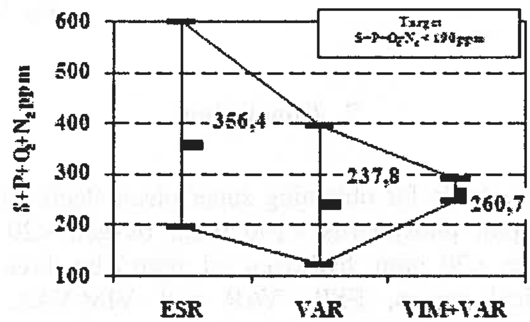

Fig. 9. Performed S+P+O_2+N_2 vs process 35NCD16 grade

6. Capability of technological routes

As it was defined by Paresys [1] and Giroud [2], the statistical capability of a process, a plant or a technological route is a function depending by average and standard deviation of a population (experimental results) and by the limits of technological targets. From this viewpoint, we have calculated 95 (2s) capability index for all the seven targets defined (S, P, O_2, N_2, S+P, S+P+O_2+N_2, H_2) before. The results of these evaluations are presented in Fig. 10 (by a global capability index) and in Fig. 11 (for each target). As it can be seen the VIM-VAR route can assure the best global capability index (95), a little over 54%.

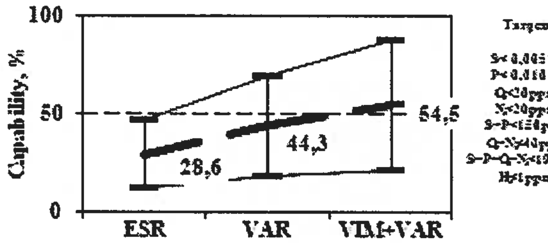

Fig. 10. Global capacity index (95) for all targets

On the basis of the evaluations for t all seven targets it was decided the improvement of the capability of VIM-VAR route by modernization of VIM and VAR plants.

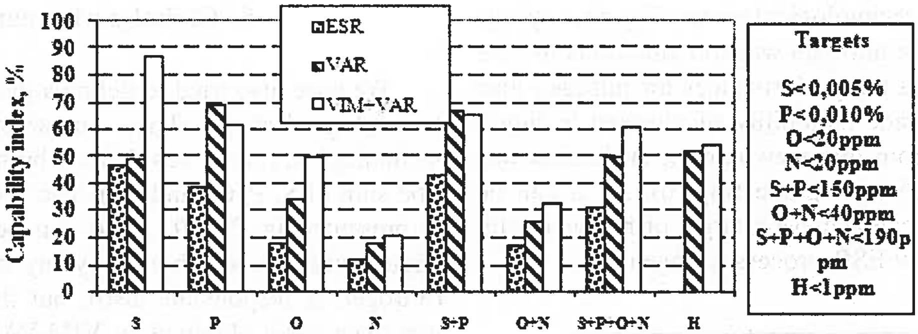

Fig. 11. Capacity index (95)

7. Conclusions

The trials for obtaining super clean steels (sulphur <50 ppm, phosphorus <100 ppm, oxygen <20 ppm, nitrogen <20 ppm, hydrogen <1 ppm,) by three technological routes, ESR, VAR and VIM-VAR, have shown:

a) sulphur target can be achieved by all technological routes, but only the VIM – VAR route had the lowest variation – about 0.001%;
b) phosphorus target cannot be performed by ESR route;
c) oxygen target can be achieved by VIM-VAR route only;
d) VAR process can achieve a target of nitrogen with about 30 ppm below the nitrogen obtained by ESR process;
e) hydrogen target can be obtained in both vacuum routes, but the VIM-VAR route has also a lower variation of hydrogen content;
f) by VIM-VAR route it can be achieved the best global capability index (95), a little over 54%;
g) to improve the quality of special steels for aero industry it was decided to improve the capability of VIM-VAR route by modernization of VIM and VAR plants.

Received: 3 April 2008.

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