Assessment of Concrete Reinforcing Bars made by the Tempcore Process (1)

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Ribbed reinforcing steel manufactured by the Tempcore process was tested for suitability by means of comprehensive investigations. The steel was tested not only with regard to the conventional properties envisaged, for example, in German Standard DIN 488, part 1 Table 1, but other material characteristics not normally the subject of investigation were also included. It can be stated that ribbed reinforcing steel manufactured by this process has the properties required by DIN 488, part 1, for steel grade III and that further investigations of a more far-reaching character give no indication that this new manufacturing process adversely affects the service properties; the steel also possesses suitable weldability for the flash, MMA and resistance methods.

Betrachtungen über nach dem « TEMPCORE »-Verfahren hergestellte Betonstähle. *In einer umfassenden Studie wurden die Anwendungsmöglichkeiten für nach dem « TEMPCORE »-Verfahren hergestellte Rippenstähle untersucht, wobei nicht nur die normalen Eigenschaften wie in der Normvorschrift DIN 488, S. 1, Tabelle 1, festgelegt Gegenstand der Studie waren, sondern darüber hinaus vorab auch andere Eigenschaften von Werkstoffen behandelt wurden, die im allgemeinen nicht untersucht werden. Man kann sagen, dass nach dem TEMPCORE-Verfahren hergestellte Rippenbetonstähle die nach Normvorschrift 488, Seite 1, für die Klasse III geforderten Eigenschaften aufweisen und dass ergänzende Untersuchungen keinerlei Anzeichen dafür erbracht haben, dass dieses neuartige Herstellungsverfahren die Gebrauchseigenschaften nachteilig beinflussen könnte. Desweiteren ist die Eignung dieser Stähle für Schweissungen nach dem RA-, E- und RP-Verfahren ausgewiesen.*

Considérations sur les aciers à béton fabriqués selon le procédé « TEMPCORE ». *Dans une vaste étude, on a examiné les possibilités d'utilisation de l'acier crénelé pour béton fabriqué selon le procédé « TEMPCORE ». L'étude n'a pas seulement visé les caractéristiques normales fixées par exemple dans la norme DIN 488, p. 1, table 1, mais on s'est aussi préoccupé d'autres caractéristiques du matériau qui ne sont pas généralement étudiées. On peut dire que l'acier crénelé pour béton, fabriqué par le procédé TEMPCORE, présente les caractéristiques exigées par la norme DIN 488, page 1, pour la catégorie III, et que les examens complémentaires n'ont pas donné d'indications selon lesquelles ce nouveau procédé de fabrication pourrait porter préjudice aux propriétés d'utilisation; on démontre également l'aptitude au soudage pour les procédés par étincelage, manuel et par résistance.*

Overwegingen over TEMPCORE betonstaal. *In een omvangrijke studie werden de toepassingsmogelijkheden van het geribde TEMPCORE betonstaal onderzocht. Deze studie was niet beperkt tot de gewone karakteristieken, b.v. volgens norm DIN 488, bl. 1, tafel 1; bestudeerd worden ook andere eigenschappen die gewoonlijk buiten beschouwing blijven. Het mag gezegd worden, dat het geribde TEMPCORE betonstaal de door norm DIN 488, bl. 1, van klasse III gestelde eisen bezit, en dat aanvullende onderzoekingen geen aanwijzing gegeven hebben, waarnaar deze nieuwe vervaardigingswijze nadeling zou kunnen zijn voor de aanwendingseigenschappen. Ook is de lasbaarheid gegeven voor het handbooglassen, het weerstandkruislassen en het stomplassen.*

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1. — INTRODUCTION

A new method to make steel rebars has been added recently to the classical processes as hot rolling and cold forming.

What is known as the Tempcore process, developed by the C.R.M. Liège in collaboration with some iron and steelmakers, takes advantage of the residual heat of the rods after hot rolling to achieve a controlled heat treatment which results in an increase of the material strength.

A somewhat near method had already been experienced by Dick [1], but not really used.

The new process seems to be reliable, so that it is possible to use it on a large industrial scale [2].

A number of works such as ARBED, Forges de Thy-Marcinelle et Monceau, and Métallurgique et Minière de Rodange-Athus(1), intend now to put on the market rebars obtained by this process. At first it is planned to produce a weldable steel of the 42/50 class and later of the 50/55 class, also weldable.

2. — THE TEMPCORE PROCESS

Several methods are available for increasing the strength of steel. For steel reinforcements according to DIN 488, sheet 1, two processes have been used up to now. In the case of bars in the as hot rolled conditions (RU) the strength is due to the nature of the microstructure and eventually to a precipitation hardening of the grains while in the cold deformed bars, near the same structural mechanisms a further increase of the strenght comes from the cold deformation.

Steels subjected to a special heat treatment, for example quenching and tempering, up to now have not been used as reinforcement for concrete. High final strength can be achieved by means of heat treatment even for low alloyed steels; however the expenditure involved in this additional operation, related to the maximum useful strength in reinforced concrete construction, exceeds that of the additional alloying elements or that of the cold forming. However, all steels are at austenisation temperature at the hot rolling stage, it is attractive to take advantage of the heat in the hot rolled product for a subsequent heat treatment. In order to achieve a useful heat treatment, it is necessary to quench the material after the last rolling stand and — in order to obtain favourable material properties — to follow with a tempering phase. The Tempcore process operates according to this idea.

The Tempcore process can be described as follows : The steel rods have a temperature of, for example, 1,000° C in the last rolling stand. After passing this stand, the steel enters a water quenching zone, in which the outer layers of the rod are cooled so intensively that martensite is formed here; the core of the rod remains at a higher temperature. At the end of this first process stage, the steel has — down to a controlled depth — a predominantly martensitic outside layer and a core which is still austenitic, within which the nonsteady temperature field will naturally lead to a series of intermediate microstructures from martensit to ferrite. The microstructures as well as the proportion of the different layers in the cross rod section can be controlled by selecting the cooling intensity in relation to the rolling temperature, rod diameter and rolling speed. The rod is cooled further at the ambiance after leaving the water cooling region. Owing to the temperature distribution the outer layer of the rod is treated once again. Hence the martensitic outer layers are subjected to a "self tempering process", provided that sufficient heat is still available in the core of the rod to provoke a sufficiently high tempering temperature of approximately 600° C. This second process stage is considered as complete when the outer layer has run through the maximum temperature value, which is caused by the residual heat in the centre "core" and the cooling condition in air (surface area, thermal conductivity).

During the third process stage — the rod is now already on the cooling bed — the material cools down normally in quiescent air.

The final microstructure, depending on :

- chemical composition,
- rod diameter,
- rolling end temperature,
- cooling intensity (in phase 1),

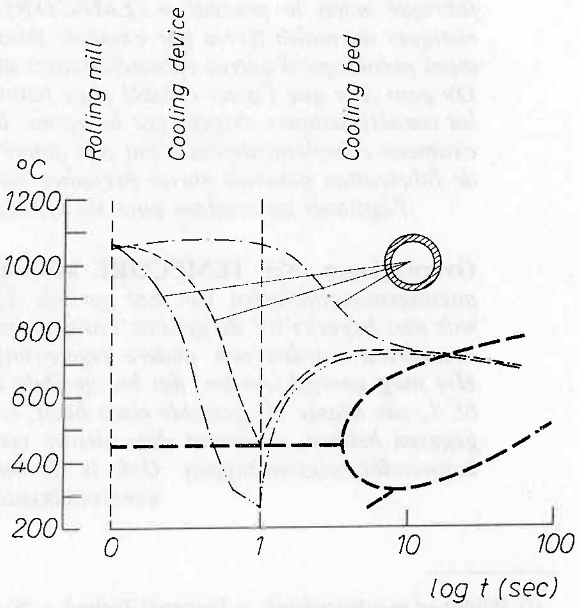

FIG. 1. Schematic representation of heat treatment in the TTT diagrams.

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(1) N.B. : and recently Hoogovens B.V.

is a mixture of ferrite and pearlite in the core, a bainitic microstructure in the transition zone and tempered martensite in the outer layer.

The overall process can be traced on a well known TTT diagram (Fig. 1); for simplicity, only the curve for "martensite start" (M_S) as well as the ferrite curve and the bainitic microstructure zone are plotted. In addition the cooling paths for surface and center are given. Hence — on viewing over the cross section — the final product must have different strength values according to the considered layer and this in the following manner :

- a high value in the outer layer;
- this is followed by a transition zone in which the strength gradually decreases to the value in the core.

This situation is represented in Figure 2.

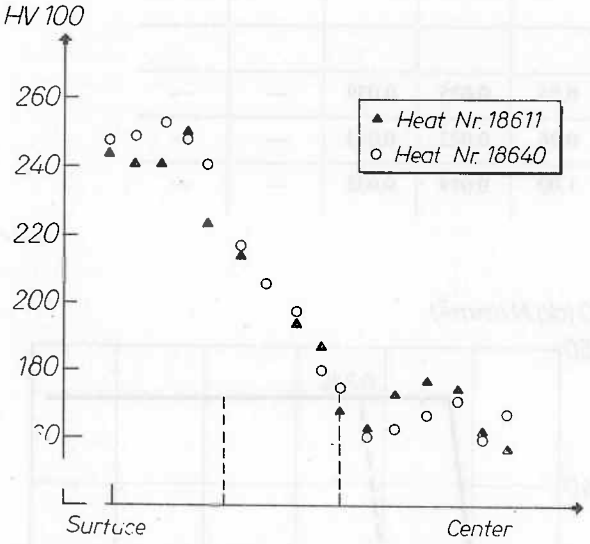

Fig. 2. Distribution of hardness values through the cross-section of Tempcore steel.

To depict further the situation, some tensile tests were carried out on machined specimens which gave the following results :

Rod diameter mm	Heat 1 (18611)		Heat 2 (18640)	
	β_s da N/mm²	β_s da /Nmm²	β_s da N/mm²	β_s da N/mm²
16	49.0	56.5	46.3	54.2
14.5 [a]	47.1	56.2	45.5	54.0
10.0 [a]	37.0	48.0	37.1	48.4
8.05 [a]	35.7	46.9	36.7	48.2
> 14.5	57.7	(68.6)	50.0	(70.8)

[a] turned specimen.

The figures in the lines 1-4 are measured values; the strength of the outer layer (>14.5) was evaluated by calculation; the yield point values are primarily of interest here.

The nonuniform microstructure over the cross section can also be seen especially clearly in Figure 3.

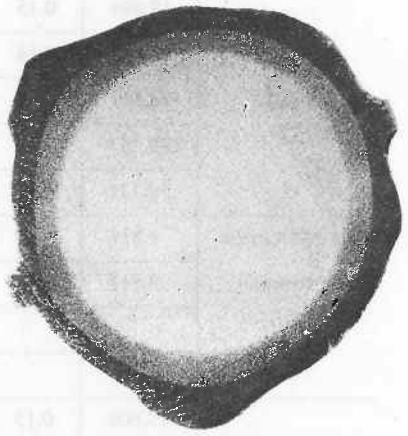

Fig. 3.

3. — INVESTIGATIONS OF THE TEMPCORE REBARS

3.1. — *Principles and aims.*

It was intended to find out whether steel rods made by the Tempcore process could be used as concrete reinforcement, i.e. whether they were fitting all the requirements of DIN 488, sheet 1, Table 1, for the steel class III U and whether the weldability was ensured for all welding procedures used in reinforced concrete construction. It is obvious that it was also necessary to test all the other properties in use, such as sensitivity to corrosion, susceptibility to brittle fracture and sensitivity to temperature. Of great importance was the investigation of the consistency of the production method, i.e., to which extent the production process accurately could be controlled ensuring a uniform quality of the product.

3.2. — *Experimental material.*

In this general investigation to test the suitability of the rebars made by the Tempcore process, altogether 23 melts were used from 3 steel mills within the dimension range varying from 8 to 28 mm. The rods were ribbed in the same way as for the steel class III U, according DIN 488.

4. — EXPERIMENTAL RESULTS

4.1. — *Chemical composition.*

The chemical compositions for individual heats are shown in Table 1. In comparison with the

TABLE 1. Chemical composition of examined heats.

Origin	Heat No.	Composition in weight per cent						
		C	Si	Mn	P	S	Nb	N
ARBED	18,894	0.15	0.06	0.97	0.022	0.013	—	0.0037
	18,640	0.14	0.03	0.92	0.015	0.012	—	0.0031
	18,611	0.18	0.04	0.98	0.021	0.013	—	0.0025
	198,357	0.19	0.03	0.78	0.036	0.022	—	0.010
	19,121	0.14	0.05	1.01	0.017	0.016	—	0.003
Thy-Marcinelle et Monceau	3,811	0.11	0.05	0.52	0.020	0.028	—	0.011
	3,817	0.15	0.04	0.66	0.029	0.027	—	0.011
MMRA	15,606	0.15	0.08	0.95	0.025	0.039	—	—
	15,609	0.15	0.07	0.96	0.022	0.033	—	—
	15,162	0.15	0.08	1.00	0.019	0.033	—	—

conventional chemical composition of the steel class III U, the considerable reduction of the carbon and also of the manganese contents will be noticed.

4.2. — *Tensile strength characteristics.*

For each melt, at least 15 specimens were tested and the following tensile characteristics measured : yield stress (β_s), tensile stress (β_z), fracture elongation (δ_{10}) and partly uniform elongation (δ_g). The characteristic values are entered into Tables 2 and 3. The results of the tensile tests with a very precise strain measurement for determining the E. modulus and of the 0.01 % proof stress are shown in Tables 4 and 5.

The main features of the tensile properties are as follows :

- the material has a marked yield point;
- the ratio of the yield point to the tensile strength is on the average 0.85 (III U, usually about 0.65);
- in spite of the fact that some strength values are high for a III U steel class, extraordinarily good uniform and ultimate elongations are always observed;
- the average E modulus is $2.05 . 10^4$ da N/mm²;
- the stress-strain curve (example Fig. 4) has a linear rise;
- the ratio $\beta_{0.01}/\beta_{0.2}$ is in the average 0.98, i.e. the 0.01 % proof stress coincides with the yield point.

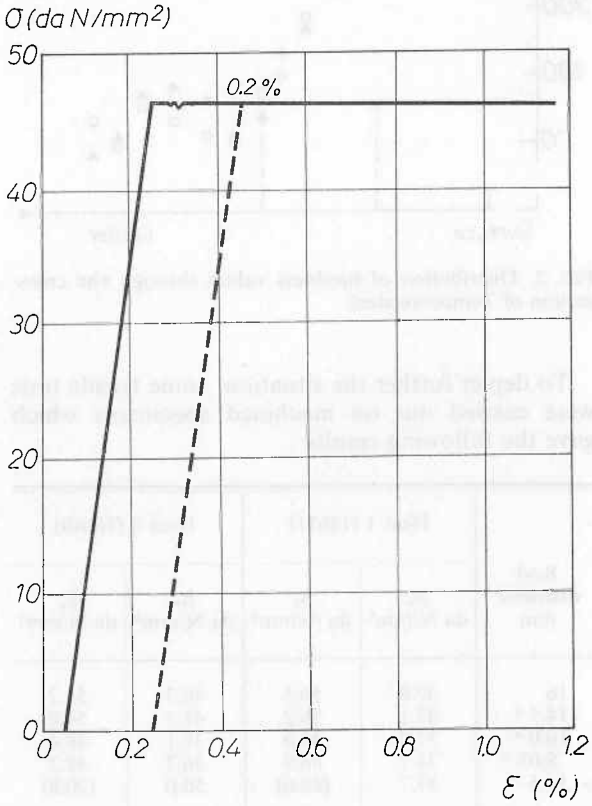

FIG. 4. Stress-strain diagram.

TABLE 2. Characteristic results of tensile tests on "Tempcore" specimens.
($\beta_s + \beta_z$ in da N/mm², δ_{10}, δ_g in %).

Heat No. Workshop	Diameter mm	Measured Value	Results				
			Average	Scattering	Minimum Value	Maximum Value	5 % Brittle
T 3,811	8	β_s	46.3	0.8	44.8	47.7	44.9
		β_z	54.6	0.7	53.6	55.6	53.4
		δ_{10}	25.4	1.8	22.5	28.8	22.4
		δ_g	16.7	—	13.1	18.1	—
T 3,817	8	β_s	50.9	2.1	48.1	54.3	47.4
		β_z	59.6	2.5	58.1	63.6	55.5
		δ_{10}	24.4	3.5	17.5	30.0	18.7
		δ_g	14.6	—	11.3	18.8	—
A 16,894	16	β_s	47.2	2.1	44.5	51.2	43.8
		β_z	55.1	1.8	52.7	58.9	52.1
		δ_{10}	23.2	1.9	19.1	25.4	20.0
		δ_g	12.1	—	12.8	16.0	—
A 18,611	16	β_s	48.4	2.1	46.3	51.3	44.9
		β_z	56.4	2.0	53.7	59.1	53.2
		δ_{10}	21.7	1.6	19.3	24.4	19.0
		δ_g	12.4	—	11.9	12.9	—

4.3. — *Reliability of production (scatter of the strength values).*

A good survey of the reliability of a production process is obtained by means of the standard deviation. This was evaluated for the yield point, tensile strength and fracture elongation in relation to melts and individual rods. The number of specimens per melt was, as a rule, 15; but for some melts, it was up to 50. The individual values per melt are given in Tables 2 and 3. From these, the following average values are calculated :

- Yield point : 1.37 da N/mm²,
- Tensile strength : 1.29 da N/mm²,
- Fracture elongation : 1.82 %.

For one melt, groups of different numbers of specimens were investigated for the purpose of studying the influence of the number of specimens. The following results were found :

	Yield point		Tensile strength		Elongation at fracture	
Heat	n	scatter da N/mm²	n	scatter da N/mm²	n	scatter %
1	15	0.8	15	0.7	15	1.8
	35	0.9	35	0.7	35	1.9
	50	0.7	50	0.8	50	2.4
2	15	2.1	15	1.8	15	1.9
	32	1.5	32	1.8	31	1.8
	47	1.9	47	1.6	47	1.8

TABLE 3. Characteristic Results of the tensile tests on "Tempcore" specimen.
($\beta_s + \beta_z$ in da N/mm^2, δ_{10}, δ_g in %.)

Heat No. Workshop	Diameter mm	Measured Value	Results				
			Average	Scattering	Minimum Value	Maximum Value	5 % Brittle
A 18,640	16	β_s	46.5	1.8	43.1	49.0	43.5
		β_z	54.1	1.1	51.5	55.4	52.3
		δ_{10}	22.4	1.5	19.6	25.3	19.9
		δ_g	13.6	—	11.7	16.0	—
A 18,640	28	β_s	47.9	0.9	46.3	49.4	46.3
		β_z	57.2	1.2	54.8	59.4	55.2
		δ_{10}	20.5	1.5	16.9	22.3	18.0
		δ_g	12.0	—	11.5	12.9	—
A 18,894	28	β_s	50.6	0.9	48.9	52.0	49.1
		β_z	59.4	1.0	57.8	60.9	57.8
		δ_{10}	20.0	1.1	17.6	21.8	18.2
		δ_g	11.0	—	11.7	14.0	—
A 18,611	28	β_s	50.7	1.1	49.1	53.1	48.8
		β_z	60.1	1.1	58.3	61.9	58.2
		δ_{10}	19.4	1.4	17.8	22.1	17.0
		δ_g	12.3	—	11.7	13.0	—
R 15,606	14	β_s	46.5	1.3	44.6	47.6	44.4
		β_z	56.7	1.0	55.5	59.2	55.1
		δ_{10}	22.5	2.1	19.3	27.8	19.1
R 15,609	14	β_s	46.4	1.8	44.5	51.4	43.4
		β_z	56.1	1.4	54.4	59.8	53.8
		δ_{10}	23.7	1.7	20.7	26.4	20.9
R 15,612	14	β_s	48.9	0.6	48.0	49.7	47.9
		β_z	58.9	0.4	58.2	59.2	58.2
		δ_{10}	20.3	1.0	18.6	21.4	18.7

TABLE 4. Results of tensile tests with precise measurement of elongation.

Diameter of bar mm	Heat No.	Characteristics of the diagram stress strain			
		$\beta_{0,01}$ da N/mm²	$\beta_{0,2}$ da N/mm²	β_z da N/mm²	Modulus E (.10³) da N/mm²
8	A I	47.1	47.1	56.2	20.3
16	A 18,894	46.6	46.3	54.0	21.0
		46.9	46.8	54.6	20.3
		45.2	45.2	53.4	20.7
		48.3	48.4	55.1	20.7
16	A 18,611	48.9	48.9	56.0	20.4
		48.7	48.7	56.2	21.0
		49.1	48.9	56.4	20.4
		51.2	51.2	56.7	21.1
		50.0	50.0	55.9	20.9
		48.1	47.4	55.4	20.6
16	A 18,640	—	45.8	52.5	20.4
		45.6	46.6	53.2	20.5
		44.2	43.3	50.9	21.1
		47.4	46.1	52.8	20.9

TABLE 5. Results of tensile tests with precise measurements of elongation.

Diameter of bar mm	Heat No.	Characteristics of the diagram stress-strain			
		$\beta_{0,01}$ da N/mm²	$\beta_{0,2}$ da N/mm²	β_z da N/mm²	Modulus E (.10³) da N/mm²
25	A II	47.6	49.9	62.7	20.4
28	A III	46.0	50.8	60.0	20.5
28	A 18,640	46.5	46.5	56.5	20.3
		46.6	47.1	56.3	20.3
		46.2	46.4	55.3	20.4
		44.7	45.5	55.2	20.4
28	A 18,894	47.9	49.1	59.1	20.5
		47.6	48.2	57.8	20.3
		46.8	49.3	57.3	20.2
28	A 18,611	48.2	48.8	59.5	20.3
		47.1	49.0	58.4	20.5
		46.6	49.8	58.6	20.5
		48.2	50.4	59.3	20.3