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Segregation of alloying elements in thermomechanically rolled medium-Mn multiphase steels

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Materials

ABSTRACT

Purpose: The aim of the paper is to assess the tendency of alloying elements to macro- and microsegregation during hot-forging and successive thermomechanical rolling of medium-Mn Al-bearing steel sheets.

Design/methodology/approach: The macro- and microsegregation of alloying elements was assessed by EDS and WDS measurements across the thickness of the roughly-forged flats and thermomechanically processed 3.3 mm sheets. The microstructure was revealed using combined methods of optical microscopy (OM) and scanning electron microscopy (SEM). Morphological features of microstructural constituents were discussed with focusing on retained austenite.

Findings: It was found that the final multiphase microstructure is mainly dependent on the Mn content and the effect of Nb microaddition is relatively low. The 3Mn steels possess very fine bainite-based microstructures whereas the steels containing 5% Mn are characterized by lath bainitic-martensitic microstructures. All the steels contain retained austenite as fine granules or layers located between bainitic ferrite laths. Some fraction of martensite-austenite (M-A) islands was also identified. The tendency of Mn and Al to macrosegregation was found after the initial hot-forging. It disappears after successive rough and thermomechanical rolling whereas thin martensite and martensite-austenite microbands as a result of Mn microsegregation locally occur.

Research limitations/implications: Further investigations are required to quantify the local changes of chemical composition especially in formed microbands and X-ray quantitative phase analysis should be applied to assess a fraction of retained austenite.

Practical implications: The knowledge of the macro- and microsegregation of alloying elements in advanced medium-Mn steels containing retained austenite can be useful in designing the thermomechanical rolling procedures of multiphase steel sheets.

Originality/value: A problem of macro- and microsegregation of Mn and Al in advanced high strength steels, which belong to the third generation of automotive steels was discussed with concentrating on Mn and Nb microaddition effects.

Keywords: Metallic alloys; Thermomechanical rolling; Multiphase steel; Retained austenite; Macrosegregation

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1. Introduction

Mechanical properties and technological formability of advanced multiphase high-strength steels (AHSS) for the automotive industry are dependent on relative fractions and stress-strain behaviour of individual microstructural constituents. Therefore, their mechanical behaviour can be compared to composite materials consisting of a matrix and reinforcing components. Ferrite forms a matrix of the 1st generation AHSS whereas the strengthening phases are martensite and/or bainite [1-12]. Retained austenite plays also the key role in forming the properties of multiphase steel sheets increasing their plasticity under conditions of strain-induced martensitic transformation [1-6]. The exceptional strength-ductility balance can be obtained for the 2nd generation AHSS, which are characterized by fully austenitic microstructure. Stabilization of austenite as a single-phase at room temperature requires adding from 18 to 30% Mn being one of the major austenite stabilizers [13-18]. They are still under semi-industrial development due to many different technological problems related to relatively poor castability, hot-working above 1150°C, corrosion resistance, Mn segregation and especially the high cost due to Mn, Al and Si alloying.

One of the new chemical composition strategies to obtain high-strength steels at reasonable plasticity is Mn alloying but to lesser extent than in high-Mn steels. Its content in recently investigated medium-Mn steels covers a range between 3 and 13%, what is enough for retention from 15 to 30% of retained austenite [19-27]. Heat treatment of medium-Mn steels comprises intercritical annealing after cold rolling or intercritical annealing and isothermal holding of steel at a bainitic transformation range to stabilize a high fraction of retained austenite with the optimal stability against strain-induced martensitic transformation. The thermomechanical processing, microalloying with Nb, Ti, V, reverse martensitic transformation and quenching and partitioning processing are another examples to obtain fine-grained bainite-based complex microstructures containing high amount of austenitic phase [20,22,24].

It was proved [22,24] that it is possible to obtain the intermediate strength-ductility range between low-Mn TRIP steels and high-Mn TRIP/TWIP steels. However, there are also some problems concerning Mn alloying, e.g. its ability to microsegregation, localized deformation, hot-working and corrosion behaviour [19-27]. A banded microstructure of ferrite / bainite-martensite-austenite is typical for TRIP steels [7,19]. The metallurgical reason for banded microstructures is segregation of Mn and Al during continuous casting [7,28]. It has been reported [7] that hard bainite-martensite-austenite bands can occur in the centre of the steel strips. Moreover, severe plastic deformation can lead to some damaged zones in these bands. Wietbrock et al. [14] reported that local differences in manganese content between dendrites and interdendritic spaces in high-Mn alloys can reach up to 7 wt.%. After homogenization treatment the microsegregation of Mn can be reduced.

In the previous works, Grajcar et al. [19,21,27] investigated the macro- and microsegregation behaviour in steels containing 3 and 5% Mn and also 1.5% Al. The tendency to macrosegregation of Mn and Al between middle and external zones of the as-cast ingots was found. Manganese content was lower whereas Al content was higher in the external zone of the ingots. The opposite was observed in the central part of ingots. The segregation of Mn and Al between central and external regions was reduced after hot forging.

2. Experimental procedure

The paper is a comparative study on the segregation behaviour of alloying elements in four high-strength Mn-Al steels containing various amount of Mn and Nb. The tendency to segregation of Mn, Al and other alloying elements was compared at the initial state (after hot forging) and after subsequent thermomechanical rolling. The chemical composition of new-developed steels given in Table 1 was designed from the point of view of maximization of retained austenite content (increased Mn content) and obtaining carbide-free bainite by low-Si high-Al concept (susceptibility to galvanizing) [1,5,7]. Mo and Nb were used to enhance strength due to grain refinement and precipitation strengthening. Special attention was paid to the effect of Nb on the grain size and segregation behaviour. All the steels have comparable contents of C, Al, Mo and Si. The difference exists between Mn and Nb contents and it is a basis for steel designation (3MnAl, 3MnAlNb, 5MnAl and 5MnAlNb). It should be noted that the steels (except 3MnAl) have low concentrations of P and S as a result of adding rare-earth elements (as mischmetal) at a final stage of a melting process.

Table 1.
Chemical composition of the investigated steels (wt. %)

	C	Mn	Al	Si	Mo	Nb	S	P
3MnAl	0.17	3.3	1.7	0.22	0.23	-	0.014	0.010
3MnAlNb	0.17	3.1	1.6	0.22	0.22	0.04	0.005	0.008
5MnAl	0.16	4.7	1.6	0.20	0.20	-	0.004	0.008
5MnAlNb	0.17	5.0	1.5	0.21	0.20	0.03	0.005	0.008

The ingots were produced by vacuum induction melting in the Balzers VSG-50 furnace (Institute for Ferrous Metallurgy, Gliwice). Liquid metal was cast in the protective atmosphere into cast iron moulds. Homogenization soaking at 1200°C for 3 hours was carried out to remove the segregation of alloying elements. Subsequently, the ingots with a mass of about 25 kg were forged at temperature range from 1200 to 900°C to a thickness of 22 mm. EDS measurements were carried out to assess the differences of chemical composition between surface (about 2 mm below surface) and central regions of hot-forged flats.

A next processing step consisted of rough rolling of flats to a thickness of about 9 mm. The final thermomechanical rolling was conducted in 5 passes to a final sheet thickness of about 3.3 mm. A semi-industrial two-high reversing mill with a roll diameter of 550 mm was used to simulate the thermomechanical treatment schedules (Institute for Ferrous Metallurgy, Gliwice). The hot-rolling schedule and multi-step cooling conditions designed on the basis of the earlier determined multi-step hot compression curves and CCT (continuous-cooling-transformation) diagrams [23,26] are presented in Fig. 1.

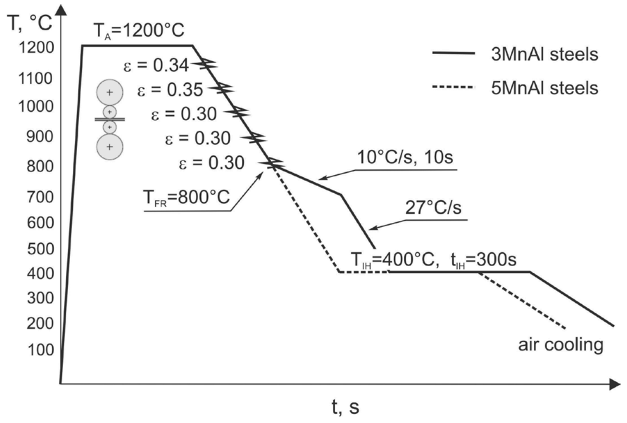

Fig. 1. Thermomechanical rolling schedule of 9 mm steel sheets to a final thickness of 3.3 mm

The 9x170x500 mm sheet samples were soaked in a furnace for 25 min. at the temperature of 1200°C. After about 20s the sheets were pushed through the rolling mill, where five deformation steps were applied. The interpass times between successive deformation steps were equal from 5 to 8s. After the final pass at about 800°C the specimens were cooled according to the full line (3MnAl and 3MnAlNb steels) or dashed line (5MnAl and 5MnAlNb steels) in Fig. 1. The steels containing 3% Mn were initially air-colled for 10s to a temperature of about 700°C followed by controlled spray cooling (water+air mist) with a rate of about 27°C/s to an isothermal holding temperature of 400°C. The 3.3x170x1200 mm steel sheets were isothermally held at 400°C for 300s in a furnace in order to enrich austenite in carbon. A final cooling step of sheets consisted of their air-cooling to room temperature. The 5MnAl steels were spray-cooled to 400°C immediately after finishing rolling (Fig. 1).

Metallographic specimens were taken along the rolling direction of the thermomechanically processed sheets. Quantitative changes of chemical composition through the sheet thickness were determined using the JCXA 8230 X-ray microanalyzer. The point microanalyses were carried out along a line with a step of 100 μm from the surface region to the centre of the sheet using the WDS technique. The accelerating voltage of 15 kV and the beam current of 30 nA were applied.

To compare microstructures after the hot forging and thermomechanical rolling metallographic investigations were carried out by the use of the LEICA MEF4A optical microscope. The specimens were etched in 10% aqueous solution of sodium pyrosulphate in order to reveal retained austenite. Morphological features of retained austenite were revealed with the SUPRA 25 and LEO GEMINI 1525 scanning electron microscopes.

3. Results and discussion

Results of chemical composition measurements for Mn and Al in the central and external zones of the hot-forged flat specimens (Table 2) are in good agreement with the bulk composition (Table 1) for all the investigated steels. The analysis of data listed in Table 2 indicates some tendency to macrosegregation of Mn and Al between the central and external zones of the specimens. It can be noted that the 3MnAl and 5MnAl steels have higher concentrations of Al and lower contents of Mn in the external regions of the hot-forged flats compared to their central parts. It was also true for the as-cast specimens [19,21]. The same tendency exists for Al in the 5MnAlNb steel. The decreasing content of Al from the external to central zones of the ingots is according with the thermodynamic calculations carried out by Pichler et al. [7]. They reported that the first formed solid phases should contain more Al than the bulk composition and hence Al is depleted in the remained liquid phase. With advancing solidification the content of Al decreases. On the other hand, the solid phase is continuously enriched in manganese during solidification [7,28]. It means that the content of Mn is the highest in the central part of the ingots. The results in Table 2 indicate that some macrosegregation of Mn and Al still exists despite the homogenization heat treatment and hot-forging applied. However, any segregations of alloying elements can be observed in Nb-microalloyed steels, where the concentrations of Mn and Al are very similar in both zones of the flat samples. A lack of the macrosegregation for Nb-microalloyed steels is very beneficial but it requires a more detailed investigations. The most probable reason for the reduction of macrosegregation of Mn and Al between the central and external regions of the flats is the overall refinement of the microstructure and shorter diffusion paths of all the alloying elements under conditions of hot working.

Table 2.
EDS measurements of the Mn and Al concentration (average values of five measurements) in the centre and external parts of the hot-forged flat specimens (wt. %)

Grade	Mn		Al	
	central	external	central	external
3MnAl	3.3	2.6	1.3	2.3
3MnAlNb	3.2	3.1	1.0	1.0
5MnAl	6.0	5.1	1.2	1.3
5MnAlNb	5.2	5.4	1.5	1.8

The micrographs in Fig. 2 show the microstructures of hot-forged steels obtained after air cooling. Due to the high hardenability all the steels are characterized by lath bainitic-martensitic microstructures and do not contain ferrite. Each prior austenite grain consists of a few bainitic or bainitic-martensitic colonies. A very beneficial feature of all the microstructures is the occurrence of retained austenite of the interlath or blocky morphology. It should be noted that it occurs already for air-cooled specimens without a multi-step cooling path used for TRIP steels. The presence of retained austenite confirms the good ability of the investigated steels for chemical stabilization of γ phase due to increased Mn contents. However, the volume fractions of retained austenite are higher for 3MnAl steels compared to 5MnAl steels, in which the high tendency to martensite forming exist. The amount of retained austenite is similar when comparing basic and Nb-microalloyed steels containing the same Mn content (Fig. 2).

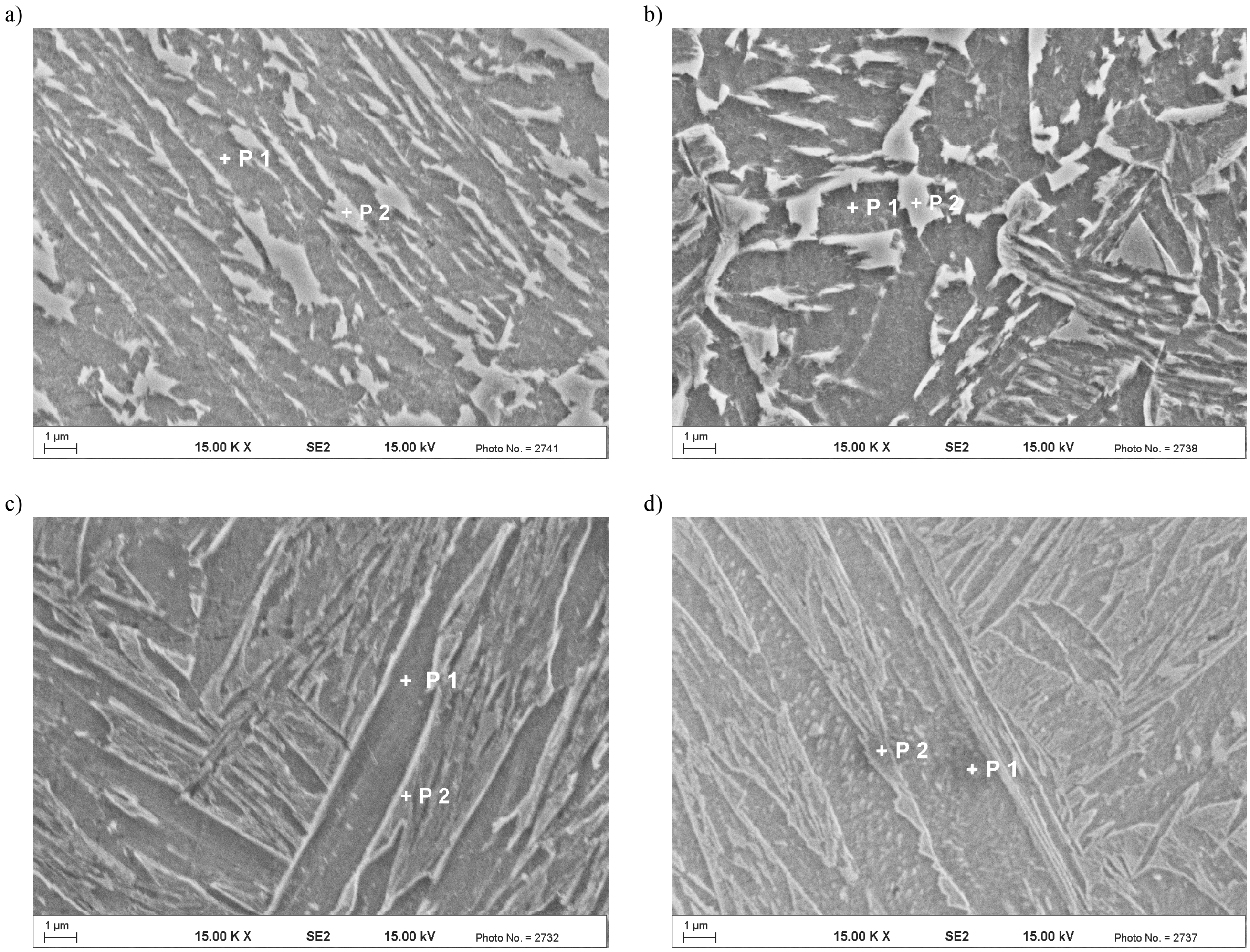

Fig. 2. Bainitic-martensitic microstructures of the 3MnAl (a), 3MnAlNb (b), 5MnAl (c) and 5MnAlNb (d) steels containing cementite and retained austenite of a different morphology depending on the Mn and Nb content (after hot forging)

The microstructures of the steels containing 3% Mn in Fig. 2a and 2b are similar to these discovered in high-strength linepipe steels by Zajac et al. [29]. They classified new, complex bainitic microstructures, which are beyond classification based on conventional concepts. The microstructure of 3MnAl and 3MnAlNb steels consists of a mixture of degenerate upper bainite and granular bainite. The characteristic feature of these microstructures is the presence of retained austenite and martensite-austenite islands instead of cementite, which is a common structural constituent of conventional bainite. The degenerate upper bainite is composed of uncompleted austenite transformation products, i.e. interlath retained austenite and martensite-austenite islands of a various shape occurring between bainitic ferrite laths. On the other hand, the granular bainite forms at the upper temperature region of bainite transformation and consists of irregular bainitic ferrite grains containing austenitic or austenitic-martensitic islands. A characteristic feature of granular bainite is a small fraction of austenite films between bainitic ferrite grains [29]. Some larger unstable austenite islands with a size between 1 and 2 µm transformed to martensite during cooling of steel to room temperature.

The microstructures of the 5Mn steels consist of bainitic-martensitic laths, retained austenite and cementite particles (Fig. 2 c,d). The bainite has a bimodal morphology. The majority of the laths has thickness between 0.1 and 0.3 µm whereas some laths are much broader. Their thickness reaches from 1 to 2 µm and they contain intra-lath particles of various size. Similar microstructures were observed by Caballero et al. [30] in high-strength Si-Mn-Cr-Mo bainitic steels. They described this type of microstructure as coalesced bainite. It forms as a result of diffusive disappearing austenite films followed by merging adjacent identically-oriented bainitic ferrite platelets. The excess carbon in the bainitic ferrite precipitates within the broad laths as cementite [30]. Some larger martensite-austenite particles can be also identified inside bainitic ferrite laths. The amount of both types of precipitates is higher in the Nb-bearing steel (Fig. 2d). Retained austenite in 5Mn steels is present as thin layers of various thickness, which are located between individual bainitic ferrite platelets or between bainite packets. Earlier results on the microsegregation of alloying elements between bainitic ferrite and austenitic regions (points P1 and P2 in Fig. 2) did not reveal the changes of chemical composition [27].

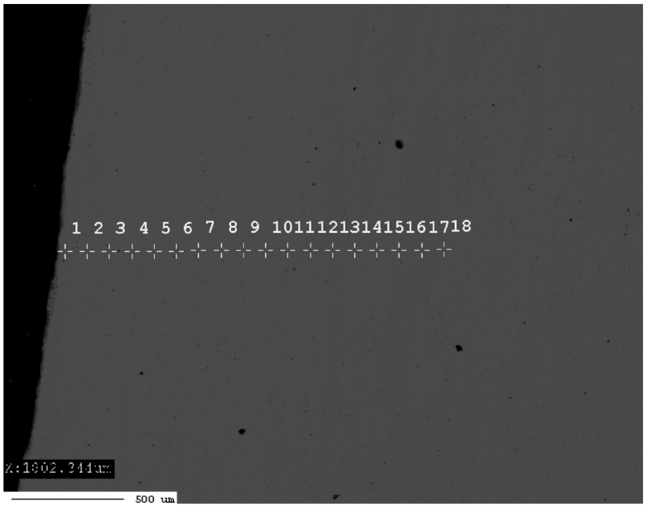

Fig. 3. Schematic of measurement points of chemical composition by WDS from the edge to the middle region of the 3.3 sheet of 3MnAl steel

Table 3.
WDS point measurements of the C, Al, Mn, Fe, Mo and Si content across the sheet thickness from the edge to the middle region of the 3.3 sheet of 3MnAl steel (wt. %)

No.	C	Al	Mn	Fe	Mo	Si
1	0.32	1.91	3.29	94.10	0.16	0.23
2	0.41	1.93	3.32	93.98	0.16	0.20
3	0.57	1.95	3.42	93.68	0.21	0.18
4	0.47	1.95	3.31	93.87	0.23	0.17
5	0.49	1.92	3.40	93.76	0.22	0.20
6	0.62	1.92	3.25	93.83	0.20	0.17
7	0.60	1.88	3.35	93.76	0.19	0.22
8	0.45	1.83	3.62	93.68	0.26	0.17
9	0.60	1.81	3.87	93.30	0.24	0.19
10	0.56	1.86	3.27	93.93	0.23	0.17
11	0.56	1.84	3.63	93.54	0.24	0.19
12	0.54	1.89	3.40	93.75	0.24	0.19
13	0.39	2.03	2.86	94.37	0.19	0.15
14	0.47	1.96	2.93	94.26	0.21	0.17
15	0.57	1.90	3.25	93.85	0.24	0.18
16	0.48	1.85	3.59	93.72	0.17	0.20
17	0.45	1.89	3.54	93.68	0.24	0.20
18	0.46	1.84	3.59	93.73	0.20	0.19
Bulk	0.17	1.70	3.30	94.38	0.23	0.22

The micrograph in Fig. 3 shows the alignment of measuring points across the thickness of the thermomechanically rolled 3MnAl steel sheet. Some globular non-metallic inclusions can be also observed. Chemical composition values measured to the half thickness of the 3.3 mm sheet correspond well with the bulk composition (Table 3). Some increased carbon content measured by WDS is typical for this kind of analysis. The detailed analysis of chemical composition of all the elements measured indicates the constancy of chemical composition along the sheet thickness. It means that the slight macrosegregation of both Mn and Al disappeared during rough and thermomechanical rolling.

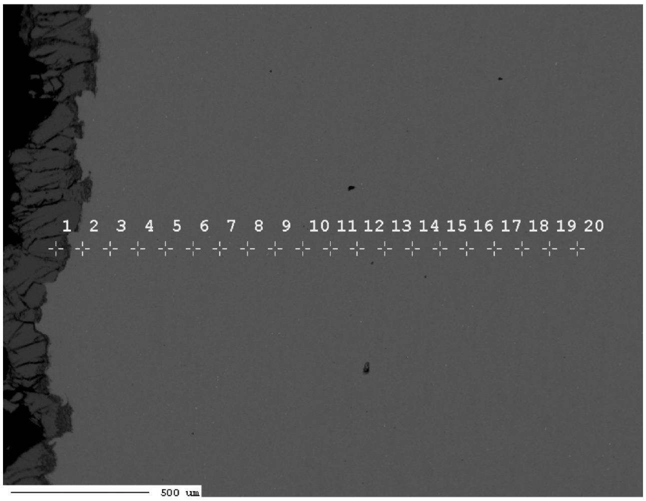

Fig. 4. Schematic of measurement points of chemical composition by WDS from the edge to the middle region of the 3.3 sheet of 5MnAl steel

Table 4.
WDS point measurements of the C, Al, Mn, Fe, Mo and Si content across the sheet thickness from the edge to the middle region of the 3.3 sheet of 5MnAl steel (wt. %)

No.	C	Al	Mn	Fe	Mo	Si
1	0.19	0.11	4.55	72.55	0.05	0.09
2	0.51	1.65	5.48	91.95	0.18	0.24
3	0.52	1.70	5.51	91.90	0.15	0.23
4	0.64	1.62	5.53	91.77	0.23	0.21
5	0.60	1.65	5.29	92.13	0.15	0.18
6	0.67	1.62	5.81	91.41	0.23	0.26
7	0.62	1.65	5.47	91.87	0.17	0.22
8	0.57	1.63	5.53	91.89	0.18	0.21
9	0.57	1.62	5.57	91.81	0.20	0.22
10	0.50	1.69	5.44	91.91	0.23	0.23
11	0.57	1.62	5.40	92.00	0.18	0.23
12	0.58	1.63	5.58	91.77	0.21	0.23
13	0.55	1.66	5.52	91.89	0.16	0.22
14	0.49	1.73	5.17	92.21	0.18	0.22
15	0.65	1.64	5.13	92.13	0.18	0.27
16	0.58	1.67	5.52	91.80	0.22	0.22
17	0.58	1.64	5.45	91.87	0.20	0.26
18	0.53	1.75	5.22	92.10	0.20	0.20
19	0.57	1.69	5.23	92.08	0.19	0.23
20	0.58	1.71	5.29	92.04	0.17	0.21
Bulk	0.16	1.60	4.70	93.14	0.20	0.20

It should be ascribed to diffusive motion of alloying elements during hot-working under conditions of repeated dynamic or static recrystallization [23,26]. The same constancy of the chemical composition across the sheet thickness occurs for the 3MnAlNb steel microalloyed with Nb. The oxide layer can be observed on the surface of the 5MnAl steel as a result of the higher manganese concentration in the steel (Fig. 4). A small fraction of non-metallic inclusions of various size and morphology can be also identified.

However, the constancy of the chemical composition of all the alloying elements across the sheet thickness is more important. This tendency occurs both for the 5MnAl steel (Table 4) and for the Nb-containing steel (Table 5). It means that the large total degree of hot deformation during successive hot forging, rough rolling and thermomechanical rolling is enough for elimination of macrosegregation of Mn and Al. Therefore, a problem of banding due to Mn segregation in the middle of the sheets is eliminated. It is confirmed by detailed investigations of the microstructure of the thermomechanically rolled steel sheets. The micrographs in Fig. 5 show the microstructures of all the investigated steels registered in the centre regions of the sheets. The significant refinement of the microstructure can be visible compared to the hot-forged specimens (Fig. 2). It concerns both the prior austenite grains and transformation products of undercooled plastically-deformed austenite. The microstructures are quite homogeneous and any macro-bands were observed.

The refinement of the Nb-free and Nb-containing steels is very similar when 3Mn and 5Mn steels are compared - respectively (Fig. 5). The type of the microstructural constituents is the same like at the initial state (Fig. 2), whereas it does not concern the quantity of individual phases. It is important that the fractions of retained austenite are higher than after hot forging. This is mainly due to deformation-induced C enrichment of austenite and its smaller particle size. It confirms the importance of the size stabilization of retained austenite in TRIP steels. Any distinct differences are visible between base and Nb-containing steels. The fraction of retained austenite is higher for 3Mn steels (Fig. 5 a,b) when compared to the steels containing higher manganese concentration (Fig. 5 c,d).

a) b) c) d)

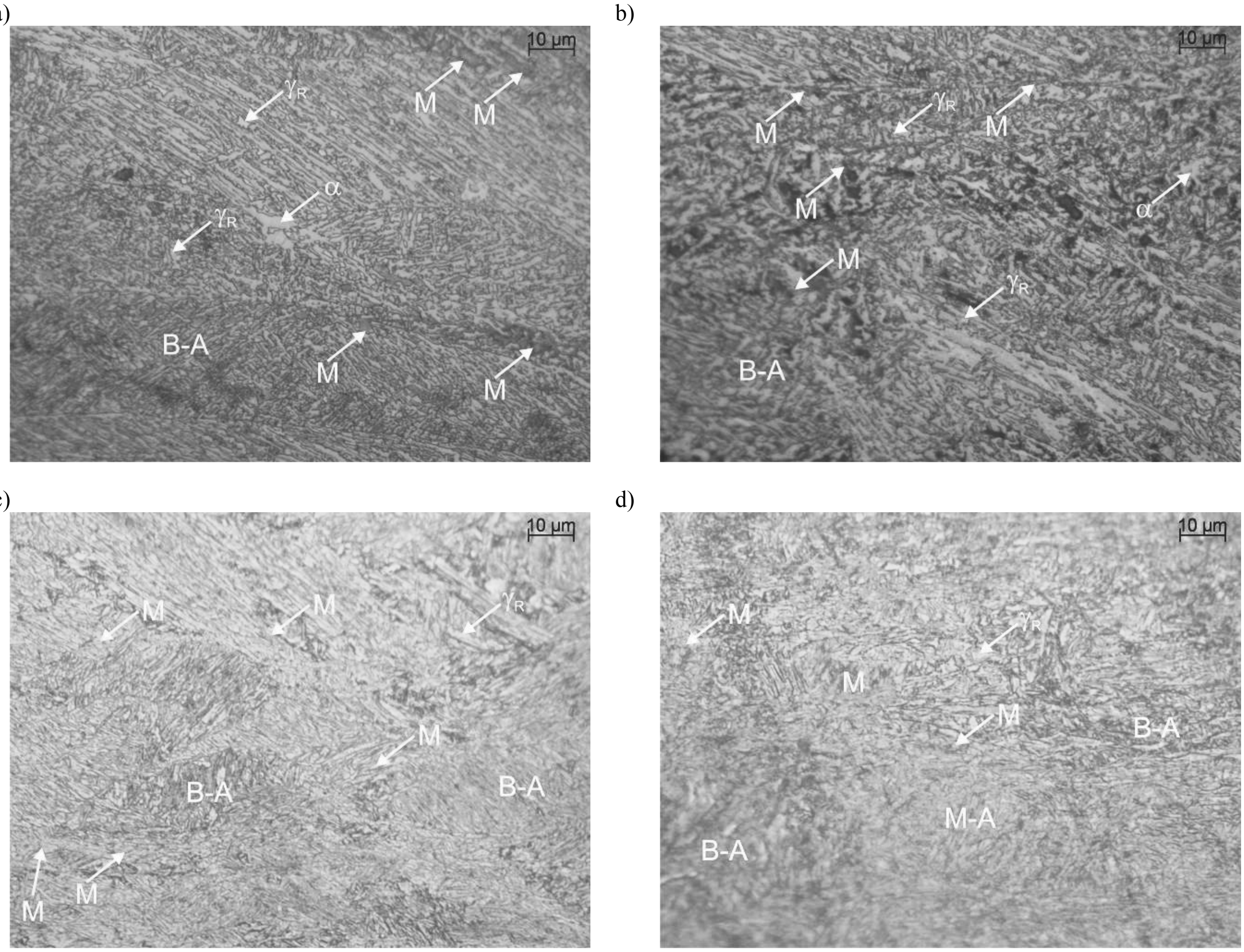

Fig. 5. Bainitic-martensitic-ferritic microstructures of the 3MnAl (a), 3MnAlNb (b) steels and bainitic-martensitic microstructures of the 5MnAl (c), 5MnAlNb (d) steels containing fine granules and interlath retained austenite (after thermomechanical rolling); α - ferrite, γ_R - retained austenite, M - martensite, B-A - bainitic-austenitic regions, M-A - martensitic-austenitic regions

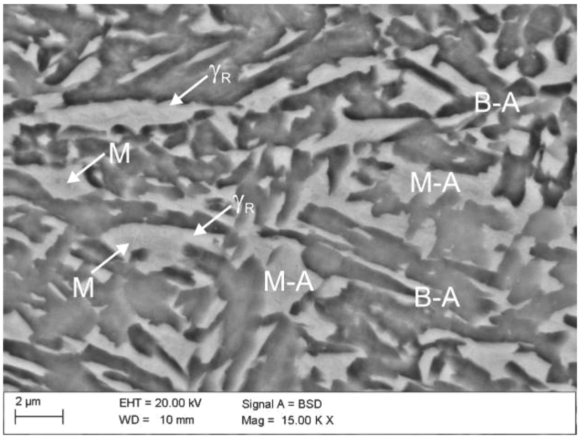

Fig. 6. Microstructure of bainitic ferrite containing interlath retained austenite and martensite-austenite islands of 3MnAlNb

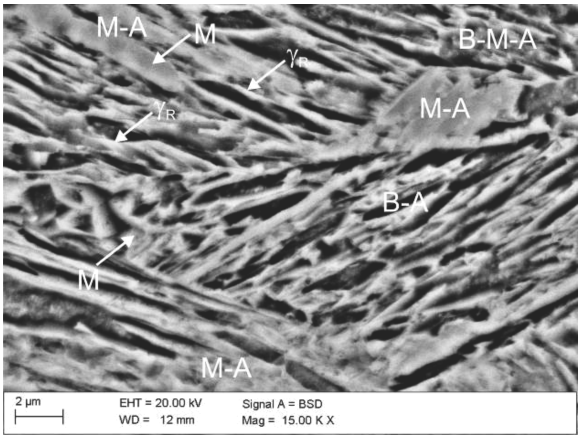

Fig. 7. Microstructure of bainitic ferrite containing interlath retained austenite and martensite-austenite islands of 5MnAlNb

Table 5.
WDS point measurements of the C, Al, Mn, Fe, Mo and Si content across the sheet thickness from the edge to the middle region of the 3.3 sheet of 5MnAlNb steel (wt. %)

No.	C	Al	Mn	Fe	Mo	Si
1	0.12	4.38	3.87	62.20	0.54	0.41
2	0.47	1.66	5.79	91.65	0.17	0.21
3	0.50	1.65	5.58	91.81	0.19	0.19
4	0.67	1.63	5.79	91.49	0.19	0.22
5	0.62	1.58	6.29	91.03	0.21	0.24
6	0.65	1.59	6.19	91.01	0.21	0.27
7	0.68	1.66	5.77	91.41	0.25	0.21
8	0.65	1.63	6.02	91.20	0.21	0.23
9	0.62	1.65	5.83	91.52	0.15	0.21
10	0.63	1.64	5.88	91.28	0.24	0.27
11	0.67	1.62	5.95	91.36	0.17	0.21
12	0.53	1.67	5.71	91.64	0.20	0.21
13	0.52	1.58	6.01	91.41	0.19	0.26
14	0.68	1.63	5.81	91.48	0.14	0.21
15	0.56	1.59	6.07	91.21	0.24	0.25
16	0.53	1.62	6.04	91.26	0.25	0.25
17	0.57	1.67	5.63	91.69	0.21	0.23
18	0.55	1.67	5.67	91.71	0.19	0.21
19	0.60	1.66	5.64	91.59	0.17	0.22
20	0.56	1.59	6.18	91.18	0.22	0.24
Bulk	0.17	1.50	5.00	92.92	0.20	0.21

The microstructure of the 3Mn steels consists of bainitic ferrite laths containing small granules and interlath retained austenite (Fig. 5 a,b). Larger blocky austenite grains with a size between 3 and 5 µm transformed during cooling of steel to room temperature forming martensite (M) or martensite-austenite (M-A) regions. They are usually located along the rolling direction forming local micro-bands, especially visible in steels containing lower Mn content (Fig. 5 a,b). It means that the macro-bands were eliminated but the steels show the tendency to local microsegregation of alloying elements (mainly Mn) revealing as thin micro-bands. The fraction of martensite and martensite-austenite islands is higher for 5Mn steels (Fig. 5 c,d). This can be probably ascribed to smaller carbon enrichment of austenite and resulting higher martensite start temperatures compared to 3Mn steels. However, this problem will be considered elsewhere using X-ray analysis.

The morphology of microstructural constituents can be analyzed in more detail using SEM. It is clearly visible in 3Mn steels that totally stable is only interlath retained austenite (Fig. 6). The elongated blocky grains with a diameter up to 2 µm are usually partially transformed into martensite. It has a place in the central part of the islands as a result of their smaller enrichment in carbon than external regions [4,25]. As a result of this many martensite-austenite (M-A) islands can be observed in Fig. 6. Interlath retained austenite is a major morphological type of γ phase in the steels containing 5% Mn. It is located between bainitic ferrite laths forming bainitic-austenitic (B-A) regions (Fig. 7). Thicker austenite layers are partially transformed into martensite and they form martensite-austenite (M-A) or bainite-martensite-austenite (B-M-A) zones. The largest M-A islands are located on prior austenite boundaries or between individual bainite packets. The quantity of undesired large bainite laths containing intra-lath cementite and M-A particles reduced considerably. This can be ascribed both to overall refinement of the prior austenite grains and its transformation products and to the same conditions of bainite forming, i.e. its forming during isothermal holding of steel at 400°C. It is not provided during slow air-cooling of steel from the finishing hot-forging temperature, hence austenite transforms into bainite at a very wide transformation temperature range forming various morphological types of bainite (Fig. 2).

4. Conclusions

Banding due to manganese enrichment in a centre segregation zone of as-cast ingots can be a technological problem for medium-Mn steels, which belong to advanced high-strength steels for the automotive industry. The obtained results indicate that there is the tendency to macrosegregation of Mn and Al between centre and external zones of the as-cast ingots. It was proved that this behaviour is partially eliminated after homogenization treatment and successive hot forging, especially for Nb-containing steels. However, manganese concentration is still higher whereas Al content is lower in the middle zone of the hot-forged flats for Nb-free steels.

The large total amount of plastic deformation and diffusive motion of alloying elements under conditions of repeated dynamic and static recrystallization during rough and final thermomechanical rolling result in the beneficial entire elimination of macrosegregation of Mn and Al across the thickness of all the steel sheets. The obtained bainite-based microstructures are characterized by high grain refinement and contain large fractions of retained austenite. Retained austenite amount is higher for 3Mn steels, where it occurs as fine granules or layers located between bainitic ferrite laths. Interlath retained austenite is mainly present for the steels containing 5% Mn. Some fraction of relative large blocky-type austenite transformed partially into martensite forming martensite-austenite or bainite-martensite-austenite islands. This behaviour occurs especially for the steels with 5% Mn, which have the higher hardenability and probably the lower C content when compared to 3Mn steels. The martensitic or martensitic-austenitic islands form thin linearly-arranged agglomerations as a result of local microsegregation of Mn. It can have the harmful effect on sheet plasticity and should be avoided by raising the finishing thermomechanical rolling temperature, which was relatively low. Any distinct effect of Nb microaddition both on the final multiphase microstructure and microsegregation behaviour was observed.

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