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THE INFLUENCE OF THE STEEL CHEMICAL COMPOSITION ONTO THE POSSIBILITIES OF USING IT IN THE PROCESS OF COLD SHAPING

Summary. In the paper it was shown what influence the steel chemical composition has onto the possibilities of using it in the process of cold shaping. Researches were made on closed sections used in constructions of automotive vehicles, made of steel quality S235JRH, S355J2H and L360MB. They included the analysis of the chemical composition, the examination of their mechanical properties and the hardness measurement. Moreover, for steel S235JRH and S355J2H the examination of microstructure was made.

WPŁYW SKŁADU CHEMICZNEGO STALI NA MOŻLIWOŚCI WYKORZYSTANIA JEJ W PROCESIE KSZTAŁTOWANIA NA ZIMNO

Streszczenie. W opracowaniu przedstawiono wpływ składu chemicznego stali na możliwość kształtowania jej metodami przeróbki plastycznej na zimno. Badania przeprowadzono na profilach zamkniętych wykorzystywanych w budowie pojazdów samochodowych, wykonanych ze stali S235JRH, S355J2H oraz L360MB. Obejmowały one analizę składu chemicznego stali, badania ich właściwości mechanicznych oraz pomiary twardości. Ponadto, dla stali S235JRH oraz S355J2H wykonano badania mikrostruktury.

1. INTRODUCTION

Contemporary vehicles are characterized by complicated structure, first of all in the ground of gradable durability of their construction [1]. Although the technology is constantly developing and new construction materials are used (composite, plastic, high-strength steel) the contribution of construction materials is still the highest which amounts to about 68% (Fig. 1.) [2].

The basic technology of producing vehicles parts is the cold malleable processing. The closed weldable shapes or half-closed produced in the process of cold forming from steel band have found wide usage in vehicle production. As a batch material, they use steel with alloy addition which have the influence on the mechanical proprieties and the corrosive resistance of a construction. The introduction of alloy addition causes the decrease of the steel ductility, which influences the possibilities of using it in the process of cold forming.

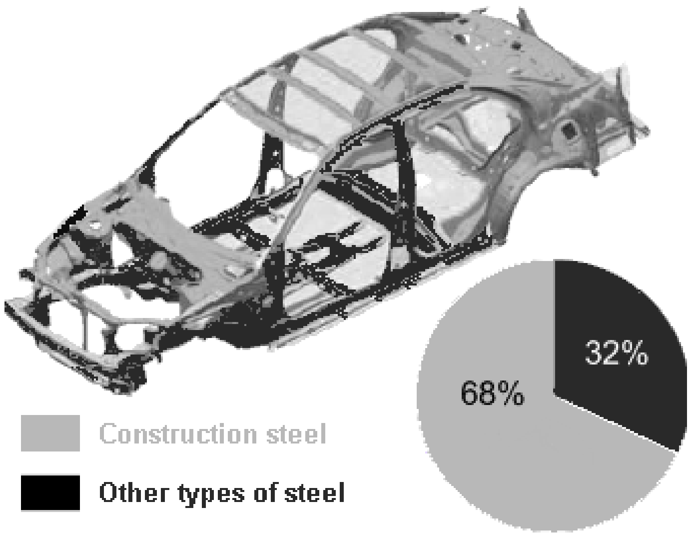


Fig. 1. The contribution of construction materials used in vehicles production [2]
Rys. 1. Udział stali konstrukcyjnych stosowanych w budowie pojazdów [2]

2. CHARACTERISTIC AND PROPERTIES OF A MATERIAL

Cold plastic processing causes the strengthening of sheet steel, improving the durability properties of a part [3].

The closed weldable shapes or half-closed are made of steel [4]:

- non alloy;
- low-alloyed fine-grained;
- low-alloyed thermal-plastic treatment;
- low-alloyed quenching and tempering.

Sheet steel is the batch material used in the production of closed weldable shapes. It should be characterized as having high resistance properties (R_m and R_e). Moreover, because of the wide range of the exploitation temperature in the contemporary vehicles (e.g. minus 20^0C) construction materials should have high resistance against brittle splitting. These proprieties are achieved by proper selection of the chemical composition, proper technology of melting and the use of malleable and thermal processing.

One of the most importing properties of steel used in the production of closed weldable shapes is its weldability. The proper weldability enables gaining needed propriety of the shape after welding.

Three factors are decisive:

- metallurgical;
- technological;
- structural.

In case of bonded shapes it is unacceptable that in the zone of heat influence (HAZ) there is a hardening structure with high hardness and low ductility. Those structures can cause the material cracking as a result of natural tension or exploitation activities. In order to reduce the risk of arising hardening structure the chemical composition of a material is modified on the grounds of coal equivalent:

$$C_E = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15, [\%] \quad (1)$$

Steel is thought to be well for welding in case when $C_E \leq 0{,}45\%$. In other cases steel requires additional operations like prior heating before welding, controlled cooling or the thermal processing [5].

The technology of manufacturing has a big influence on the proprieties of the steel band used in shapes. In order to have the fine-grained structure of steel the procedure of blowing the metal bathing by nitrogen or calcium cyanamide is used. Regulated steel rolling, which is done in two ranges of temperature, affects the creation of fine-grained ferritic structure. The prior rolling is done in relatively high temperature, however the final rolling is done in low temperature in small deformability and numerous culverts with fast cooling [6].

The elementary group of steel used in the welding shapes is the non alloy construction steel. The steel belongs to quality steel. The chemical composition and the mechanical proprieties of steel are given in the norms PN-EN 10025-1:205 (U) [4] and PN-EN 10025-2:205 (U) [7]. Chosen types of steel and the required chemical composition are shown in the table 1, and in the table 2 their mechanical proprieties.

Table 1

The chemical composition of examined types of non alloy construction steel [7,12]

Steel type	*Maximal element concentration [%]*						
	C_E	C	Si	Mn	P	S	N
S235JR	0,35	0,17	-	1,40	0,035	0,035	0,012
S355JR	0,45	0,24	0,55	1,60	0,035	0,035	0,012
L360MB	0,41	0,16	0,45	1,60	0,025	0,020	-
C_E – coal equivalent							

Table 2

The mechanical proprieties of examined types of non alloy construction steel [7,12]

Steel type	*Mechanical proprieties*			
	R_{eH} [MPa] min.	R_m [MPa]	A [%] min.	KV [J] (for 20°C) min.
S235JR	235	360÷510	26	27
S355JR	355	470 ÷ 630	21	27
L360MB	360 ÷ 510	460	20	24

2.1. Results of examination

The examinations of chosen steel were to define its usefulness in the process of cold shaping on the basis of the chemical composition analysis, the mechanical proprieties and the hardness distribution in the zone welded by induction and in the bending site.

The shapes which were used in the examination:

a) 100x150x6,3 S235JRH steel (thermal-plastic treatment batch),
b) 100x100x4 S355J2H steel (thermal-plastic treatment batch),
c) Ø 273x6,35 L360MB steel.

Chosen examination results were averaged and presented in a graphical form and in a table.

2.2. Chemical composition analysis

The chemical composition analysis was made by the spectral method coherent with PN-97/H-04045 [8] on Spektrolab M5. The analysis results were presented in table 3.

Table 3

Results of the chemical composition analysis of the examined steel

Steel type	*Content of chosen elements [%]*							
	C	Mn	Si	P	S	Cr	Cu	**C_E**
S235JRH	0,07	0,39	0,02	0,011	0,007	-	0,09	0,14
S355J2H	0,18	1,33	0,21	0,013	0,009	-	0,12	0,40
L360MB	0,05	0,58	0,26	0,012	0,006	0,03	0,08	0,16
C_E – coal equivalent								

The chemical composition analysis shown its compatibility with the values presented in norms.

2.3. Mechanical proprieties

The mechanical proprieties of the examined steel were stated coherently with the norms PN-EN1002-1 [9] and PN-EN 10219-1 [10] on the strength machine Wolpert Zwick 600 kN.

The average examination results were presented in the table 4. On their basis it was stated that the mechanical proprieties have higher values than those given in PN-EN 10219-1.

The examination results of tensile strength and the ductility limit for each steel and single samples are presented at fig. 2 ÷ 5.

Table 4

Mechanical proprieties of bands of S355J, S235JR and L360MB steel

Steel types	size [mm]		$R_{0,2}$ [MPa]	R_m [MPa]	A [%]
S235JRH	6,3	according to PN	min. 235	360÷510	min. 26
		measured scope	346 ÷ 408	437 ÷ 452	31 ÷ 44
		average value	387	446	39
S355J2H	4	according to PN	min. 355	470÷630	min. 22
		measured scope	513 ÷ 539	597 ÷ 620	29 ÷ 40
		average value	531	608	36
L360MB	6,35	according to PN	$R_{t0,5}$ 362 ÷ 460	min. 460	min. 20
		measured scope	386 ÷ 422	493 ÷ 538	21 ÷ 33
		average value	404	507	28

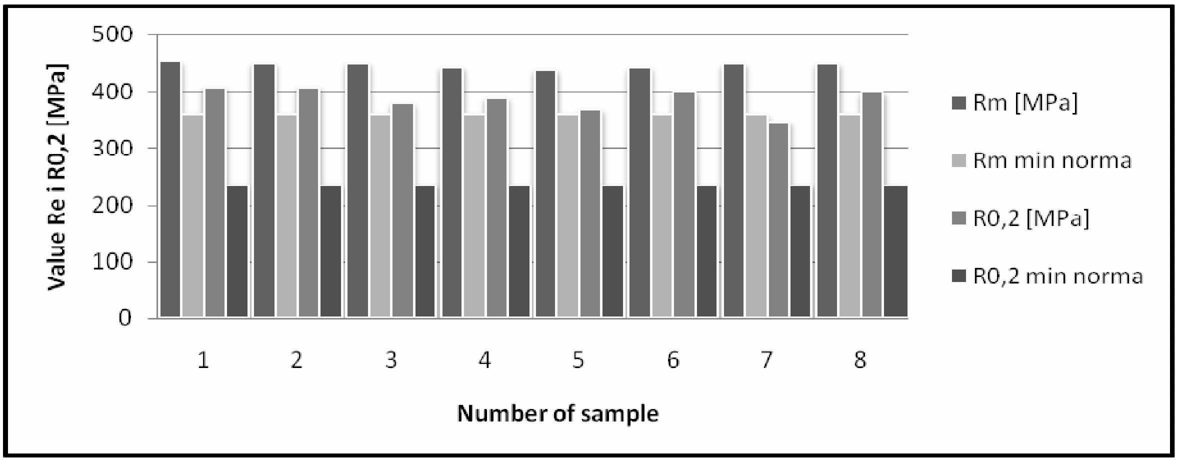


Fig. 2. Tensile strength and the ductility limit of a shape 100x150x6,3mm of S235JRH steel
Rys. 2. Wytrzymałość na rozciąganie oraz granica plastyczności profilu 100x150x6,3mm ze stali S235JRH

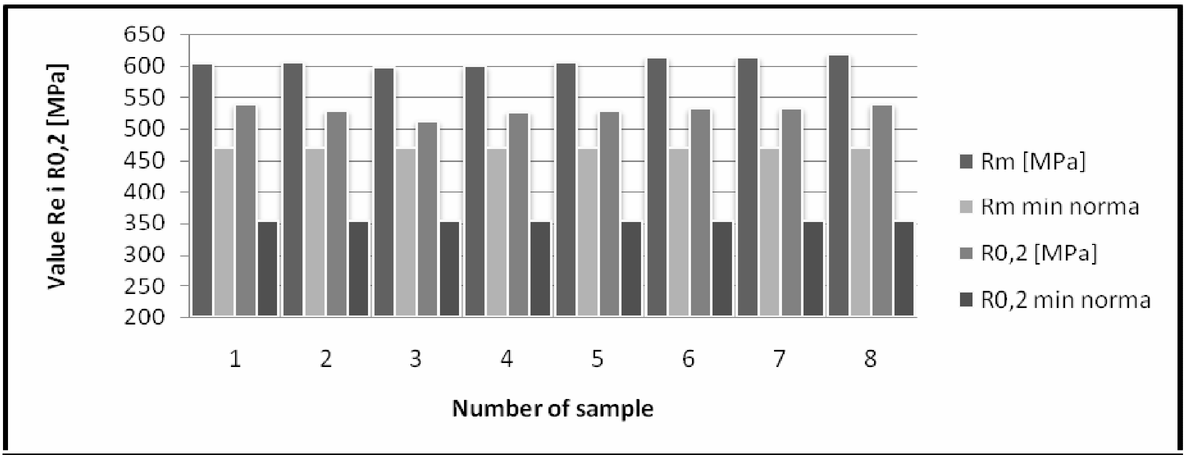


Fig. 3. Tensile strength and the ductility limit of a shape 100x100x4mm S355J2H steel
Rys. 3. Wytrzymałość na rozciąganie oraz granica plastyczności profilu 100x100x4mm ze stali S355J2H

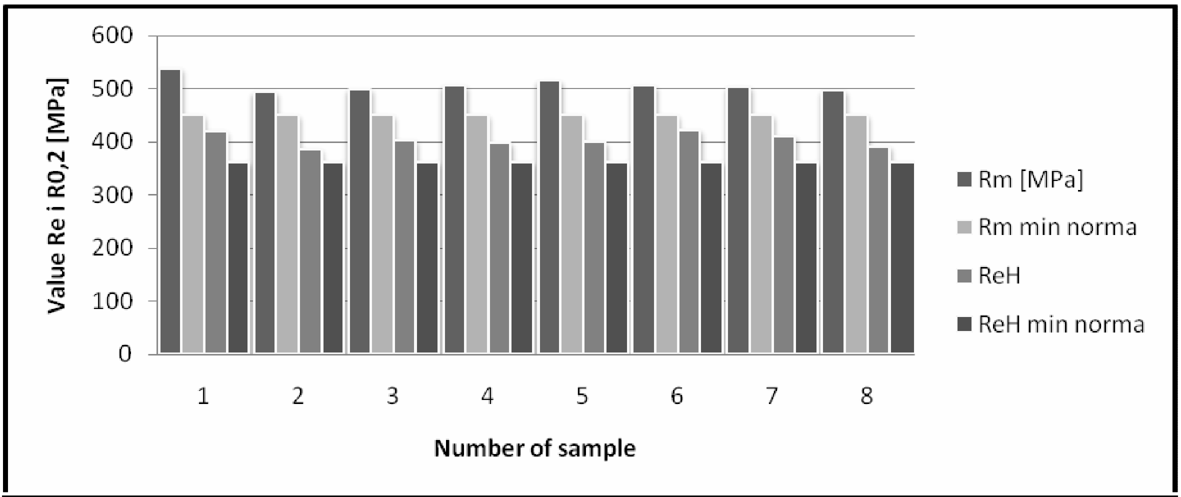


Fig. 4. Tensile strength and the ductility limit of a shape ϕ273x6,35mm L360MB steel
Rys. 4. Wytrzymałość na rozciąganie oraz granica plastyczności profilu ϕ273x6,35mm ze stali L360MB

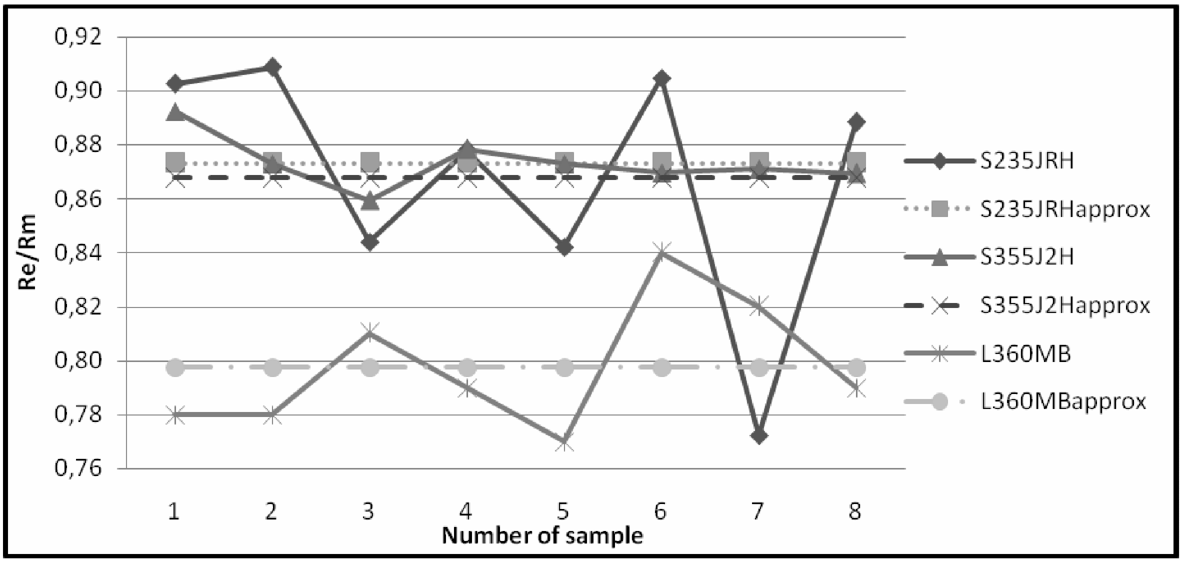


Fig. 5. R_e/R_m proportion for each steel
Rys. 5. Stosunek R_e/R_m dla poszczególnych stali

From the examination it is seen that the samples of S355J2H steel ($R_{mapprox}$ = 608 MPa) containing at least 1,33% of manganese and small amount of silicon, phosphorus, sulphur and copper have the highest strength (table 4). Simultaneously the samples made of the steel are characterised by a large amount of unit elongation (A_{approx} = 36%) which shows its usefulness in cold plastic processing.

Samples made of L360 MB steel, containing a small amount of coal (0,05%) and additions as manganese, silicon, phosphorus and chromium (table 4) are characterised by high value of strength ($R_{mapprox}$ = 507 MPa) but the smallest values of unit elongation among examined steel (A_{approx} = 28%). The samples of L360MB steel, as the only ones, included chromium (0,03%) and had the highest amount of silicon (0,26%) which influenced the steel ductility.

2.4. Hardness measurement

The hardness measurement was made according to norm PN-EN ISO 6507-4 [11] by the Vickers method with the load 98 N (HV 10). The detailed results of these measurements were presented on figures 6 ÷ 10.

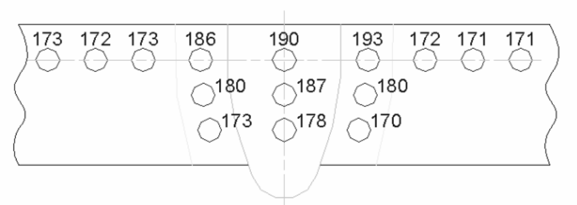


Fig. 6. Hardness distribution HV 10 on the section of welding cold forming shape 100x150x6,3 mm of S235JRH steel in the welding zone

Rys. 6. Rozkład twardości HV 10 na przekroju zgrzewanego profilu zimnogiętego 100x150x6,3 mm ze stali S235JRH w obszarze zgrzeiny

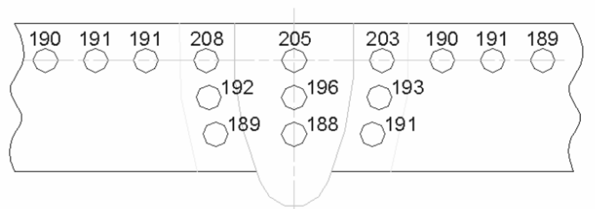


Fig. 7. Hardness distribution HV 10 on the section of welding cold forming shape 100x100x4 mm of S355J2H steel in the welding zone

Rys. 7. Rozkład twardości HV 10 na przekroju zgrzewanego profilu zimnogiętego 100x100x4 mm ze stali S355J2H w obszarze zgrzeiny

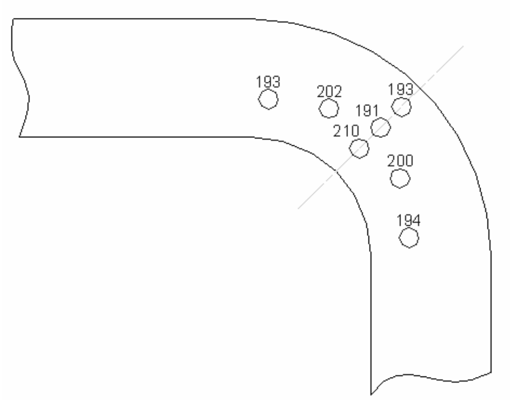


Fig. 8. Hardness distribution HV 10 on the section of bending shape 100x150x6,3 mm of S235JRH steel

Rys. 8. Rozkład twardości HV 10 w obszarze gięcia profilu 100x150x6,3 mm ze stali S235JRH

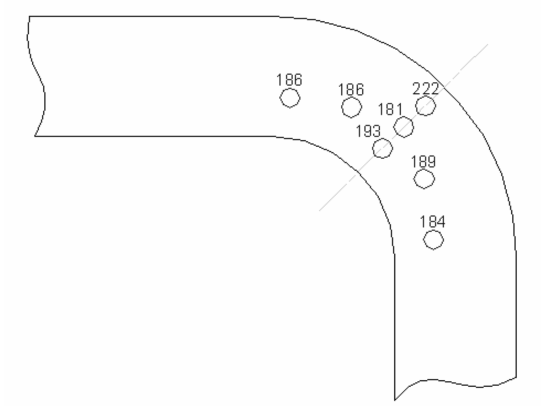


Fig. 9. Hardness distribution HV 10 on the section of bending 100x100x4 mm of S355J2H steel

Rys. 9. Rozkład twardości HV 10 w obszarze gięcia profilu 100x100x4 mm ze stali S355J2H

The achieved measurements proved predictable growth of hardness in the zone of welding, HAZ and in the zone of bending.

In case of steel S235JRH the hardness growth in the zone of welding and HAZ amounted about 10,5% (z 172 HV do 190 HV), however in the zone of bending about 9% (do 210 HV). The distribution of measured hardness for steel S235JRH were presented in Fig. 6 and 8.

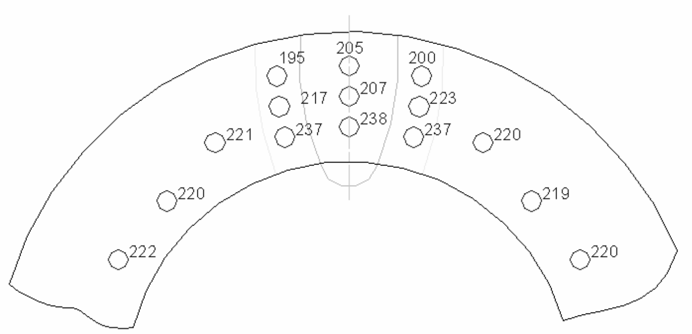


Fig. 10. Hardness distribution HV 10 on the section of welding cold forming shape ø273x6,35mm of L360MB in the welding zone
Rys. 10. Rozkład twardości HV 10 na przekroju zgrzewanego profilu zimnogiętego ø273x6,35mm ze stali L360MB w obszarze zgrzeiny

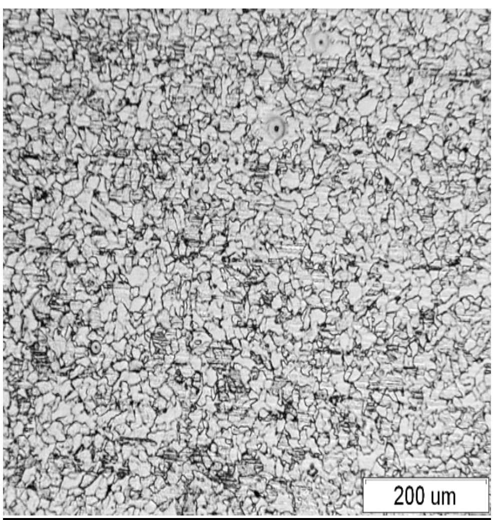
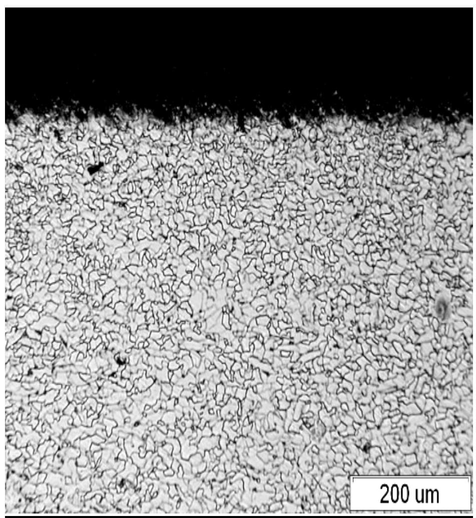
In the samples taken from the shapes made of steel S355J2H with the hardness 190HV in the welding and its HAZ the hardness amounted to 208 HV (growth about 9,6%) and in the welding zone to 222HV (hardness growth about 18,5%) (Fig. 7 and 9).

The zone welding made in the perimeter of the pipe shape Ø273x6,35 mm of L360MB steel is characterised by the welding hardness 205-238 HV and HAZ 195-237 HV with the steel hardness 220 HV (Fig. 10). In the welding zone and HAZ the hardness growth about 7,5%.

2.5. Microstructure examination

The microstructure examination in the welding joint, the welding zone and the rectilinear sector of the shape of S235JRH and S355J2H steel was made on metallographic grinds treated with 2% nitric acid in ethyl alcohol (M1Fe).

2.6. Results of structural analysis

S235JRH steel	 Fig. 11. Microstructure in the rectilinear section of welded shape Rys. 11. Mikrostruktura w odcinku prostoliniowym kształtownika zgrzewanego	 Fig. 12. Microstructure in bending section of welded shape (near surface) Rys. 12. Mikrostruktura w odcinku giętym kształtownika zgrzewanego (przy powierzchni)

S235JRH steel

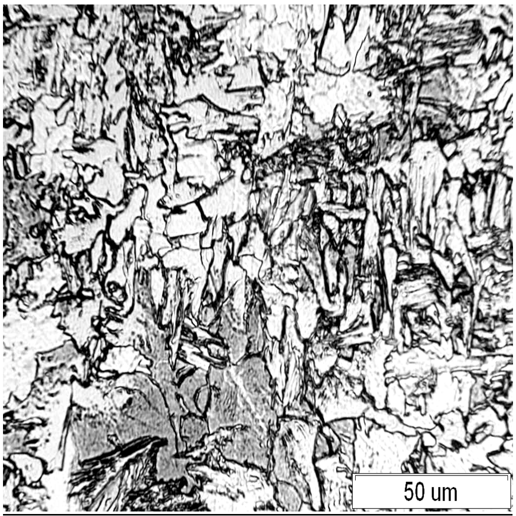


Fig. 13. Microstructure in the joint section
Rys. 13. Mikrostruktura w obszarze połączenia

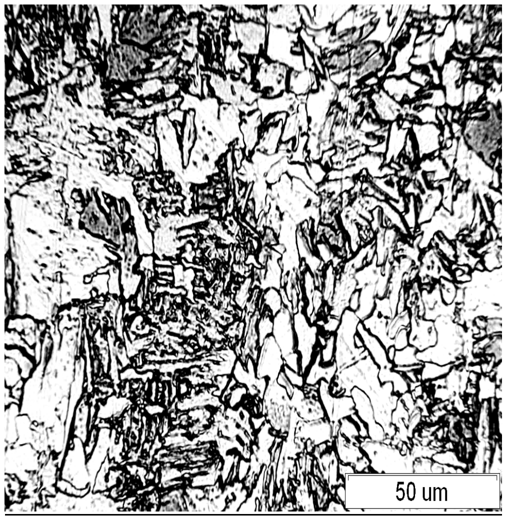


Fig. 14. Microstructure in HAZ
Rys. 14. Mikrostruktura w SWC

S235JRH steel

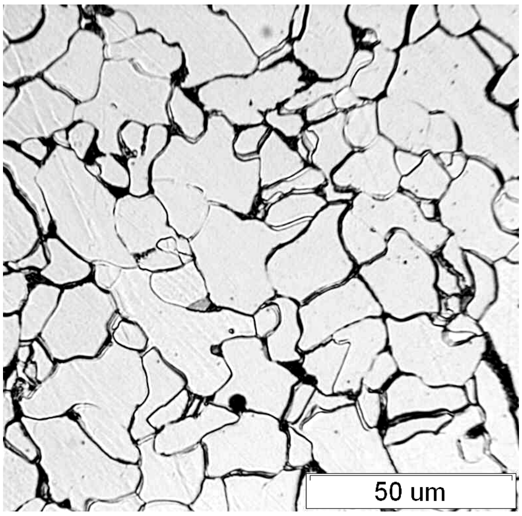


Fig. 15. Microstructure in the joint section
Rys. 15. Mikrostruktura w obszarze połączenia

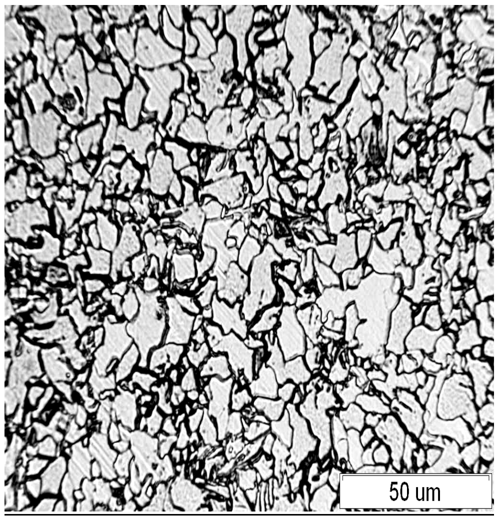


Fig. 16. Microstructure in HAZ
Rys. 16. Mikrostruktura w SWC

The shapes made of S235JRH steel are characterized by fine-grinded ferritic-pearlite structure (Fig. 11 – 12). They are characterized by high quality of producing and are free of welding errors (Fig. 13 – 16). In the welding axis there is a ferritic-banit structure (Fig. 13 and 14).

S355JRH steel

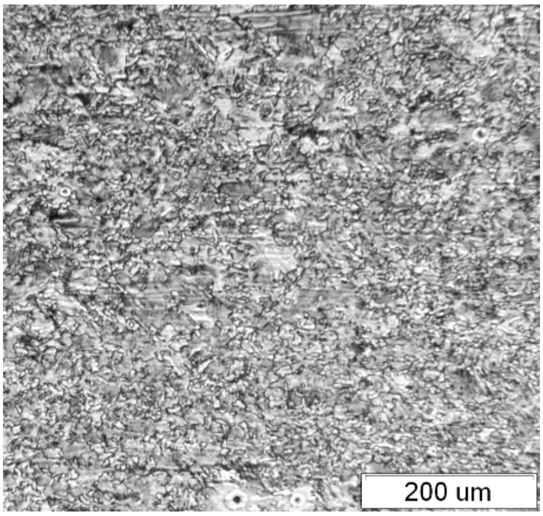


Fig. 17. Microstructure in the rectilinear section of welded shape
Rys. 17. Mikrostruktura w odcinku prostoliniowym kształtownika zgrzewanego

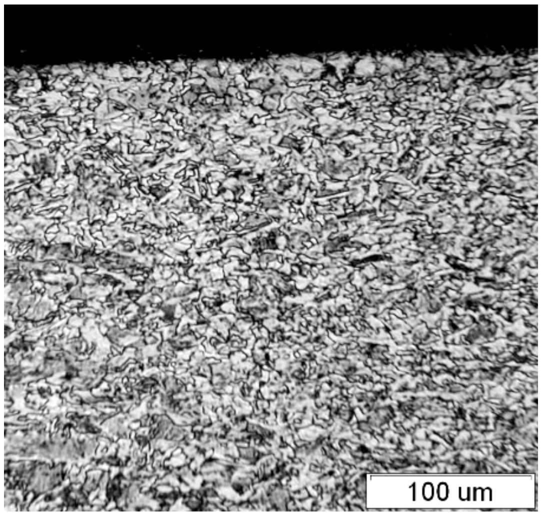


Fig. 18. Microstructure in bending section of welded shape (near surface)
Rys. 18. Mikrostruktura w odcinku giętym kształtownika zgrzewanego (przy powierzchni)

S355JRH steel

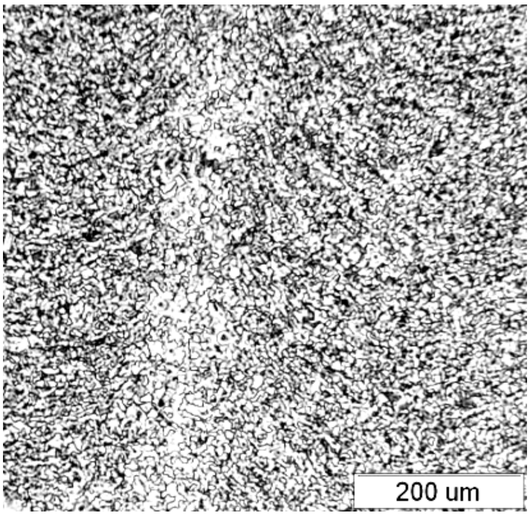


Fig. 19. Microstructure in the joint section
Rys. 19. Mikrostruktura w obszarze połączenia

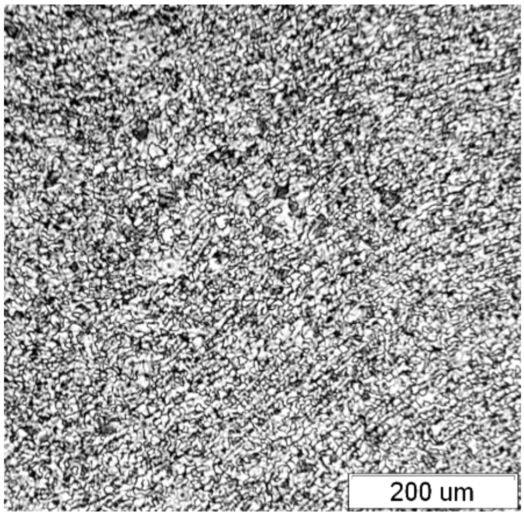


Fig. 20. Microstructure in HAZ
Rys. 20. Mikrostruktura w SWC

S355JRH steel

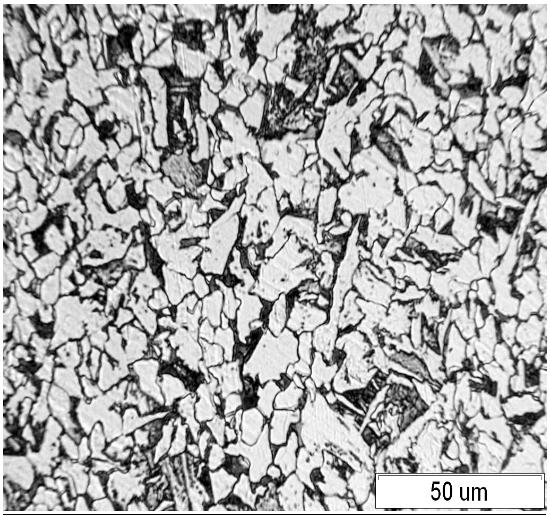


Fig. 21. Microstructure in the joint section
Rys. 21. Mikrostruktura w obszarze połączenia

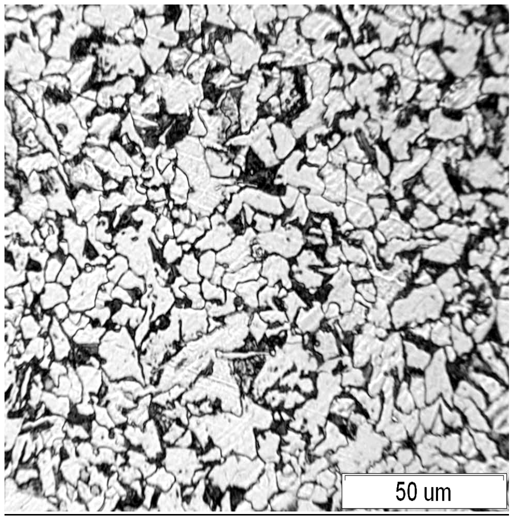


Fig. 22. Microstructure in HAZ
Rys. 22. Mikrostruktura w SWC

In case of S355J2H steel there is also ferritic-pearlite structure (Fig. 17 and 18). In the welding zone and HAZ (Fig. 19 – 22) there are no welding errors. In this zone there is a ferritic-banit structure.

3. CONCLUSIONS

On the basis of realized results analysis of the chemical composition, strength proprieties, hardness disposal S235JRH, S355J2H, L360MB steel and microstructure analysis steel S235JRH and S355J2H it was stated that:

- S355J2H steel has the highest strength (R_m = 597 ÷ 620 MPa). Among the examined steel it has the highest content of coal (0,18%) and manganese (1,33%). Moreover the sample was exposed to thermal-plastic treatment.
- L360MB steel shapes have lower than S355J2H steel strength (R_m = 493 ÷ 538 MPa). In their chemical composition there was 0,05% of coal and 0,57 – 0,67% of manganese and 0,02-0,04% of copper. This steel was also exposed to thermal-plastic treatment.
- lowest strength proprieties have welding shapes of S235JRH steel (R_m = 437 ÷ 452 MPa). This steel was normalized, it contained 0,07% of coal and the lowest amount of manganese - 0,39%.
- S235JRH and S355J2H steel are characterized by the highest values of unit elongation (respectively A_{approx} = 39 i 36%) which contained the lowest amount of silicon (respectively 0,02 i 0,21%) and highest than in samples of L360MB steel amount of sulphur (respectively 0,007 i 0,009%)
- samples of L360MB steel hale the lowest value of unit elongation (A_{approx} = 28%), containing chromium (0,03%) and the lowest amount of sulphur (0,006%).
- on the basis of the examination it was stated that low amount of coal, manganese and phosphorus and high amount of sulphur has the biggest influence on steel ductility.

On the basis of these examinations it was stated that there is an influence of steel chemical composition onto the possibilities of using it in cold shaping. The increase of manganese and coal amount has not a positive influence on the steel ductility. Simultaneously, the increase of amount of these elements positively influences the strength growth of steel (table 4).

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