

# Wearing Quality of Austenitic, Duplex Cast Steel, Gray and Spheroidal Graphite Iron

S. Pietrowski\*

Department of Materials Engineering and Production Systems, Technical University of Łódź  
Stefanowskiego 1/15 Street, 90-924 Łódź, Poland

\*Corresponding author. E-mail address: stanislaw.pietrowski@p.lodz.pl

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## Abstract

The current work presents the research results of abrasion wear and adhesive wear at rubbing and liquid friction of new austenitic, austenitic-ferritic (“duplex”) cast steel and gray cast iron EN-GJL-250, spheroidal graphite iron EN-GJS-600-3, pearlitic with ledeburitic carbides and spheroidal graphite iron with ledeburitic carbides with a microstructure of the metal matrix: pearlitic, upper bainite, mixture of upper and lower bainite, martensitic with austenite, pearlitic-martensitic-bainitic-ausferritic obtained in the raw state. The wearing quality test was carried out on a specially designed and made bench. Resistance to abrasion wear was tested using sand paper P40. Resistance to adhesive wear was tested in interaction with steel C55 normalized, hardened and sulfonitrided. The liquid friction was obtained using CASTROL oil. It was stated that austenitic cast steel and “duplex” are characterized by a similar value of abrasion wear and adhesive wear at rubbing friction. The smallest decrease in mass was shown by the cast steel in interaction with the sulfonitrided steel C55. Austenitic cast steel and “duplex” in different combinations of friction pairs have a higher wear quality than gray cast iron EN-GJL-250 and spheroidal graphite iron EN-GJS-600-3. Austenitic cast steel and “duplex” are characterized by a lower wearing quality than the spheroidal graphite iron with bainitic-martensitic microstructure. In the adhesive wear test using CASTROL oil the tested cast steels and cast irons showed a small mass decrease within the range of 1÷2 mg.

**Keywords:** New Materials and Technologies, Austenitic Cast Steel, “Duplex” Cast Iron, Abrasion Wear, Adhesive Wear

## 1. Introduction

Nowadays the pumps elements which work in the drainage systems in the coal mines, ore material and mineral mines, oil and gas outputs, stationary and pharmaceutical industries and sewage farms are made of austenitic cast steel or austenitic-ferritic cast steel (duplex). In these systems media and water are chemically aggressive regarding the presence of chlorides, salt, sulphates, phenols and different acids as well as polluted with alluvium fractions, quartz, coal and other spars. It requires the use of cast steels resistant to corrosion, erosion and abrasion wear. Traditionally austenitic cast steels can have little amounts of ferrite to improve its welding properties; however, they have a low content of carbon. The chemical composition of the

austenitic cast steels is paced in the following range: 0.03÷0.15% C; 16.00÷26.00% Cr; 8.00÷36.00% Ni; 0.00÷8.00% Mo; 0.25÷1.50% Si; 1.00÷2.00% Mn; 0.10÷0.50% N.

Austenitic-ferritic cast steels which are commonly known as “duplex” should contain about 50% of both austenite and ferrite (1:1). They have higher mechanical properties than the austenitic cast steels, better resistance to stress corrosion, welding properties and fatigue strength and lower dilatibility. In comparison to austenitic cast steels, “duplex” steels have a decreased carbon content of about 0.02÷0.04% and nickel of about 1.00÷8.50%. The concentration of other elements is similar to austenitic cast steel.

Austenitic cast steel and “duplex” are subjected to thermal treatment, thermohardening and age hardening. Thermoharde-

ning is carried out at the temperature of  $1000\div 1100^{\circ}\text{C}$  for  $4\div 8$  h and then the steels are cooled in water. Ageing treatment is carried out at the temperature between  $400\div 500^{\circ}\text{C}$  for  $4\div 68$  h and then the steels are cooled in the ambient air. After the thermal treatment the mechanical properties of austenitic cast steel are placed in the following range:  $R_{p0,2} = 350\div 430$  MPa;  $R_m = 730\div 850$  MPa;  $A_5 = 35\div 45\%$ ;  $HB = 180\div 201$ ;  $KV = 95\div 105$  J, and “duplex” in the range of:  $R_{p0,2} = 650\div 800$  MPa;  $R_m = 900\div 1100$  MPa;  $A_5 = 35\div 45\%$ ;  $HB = 260\div 320$ ;  $KV = 120\div 140$  J [1÷42].

It follows from the state of arts that the abrasion wear tests, adhesive wear tests and comparing to other materials of the higher wearing quality have not been carried out for neither of the cast steels. In connection to this, the aim of the present work was to present the results of the abrasion and adhesive wear tests in rubbing friction and when austenitic cast steel and “duplex” are smeared with oil as well as comparing them with other materials.

## 2. Methodology of the research

The tested cast steel was subjected to thermotreatment at the temperature and for the time  $1050^{\circ}\text{C}/8\text{h}$  and then it was cooled in water and later was subjected to ageing treatment in the conditions of  $450^{\circ}\text{C}/8\text{h}$  and cooled in the ambient air. After the thermal treatment the average hardness of the austenitic cast steel was  $134$  HB, and  $265$  HB of the “duplex”. The counter specimen was made of steel C55, hardened, sulfonitrided and normalized. The hardness of the hardened counter specimen was  $49$  HRC, of the sulfonitrided layer it was  $517$   $\mu\text{HV}.1$  and of the normalized it was  $225$  HB. The wearing quality was tested using the device presented in Figure 1 (a÷c).

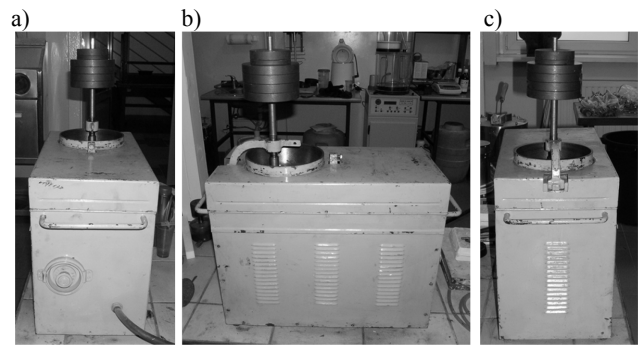


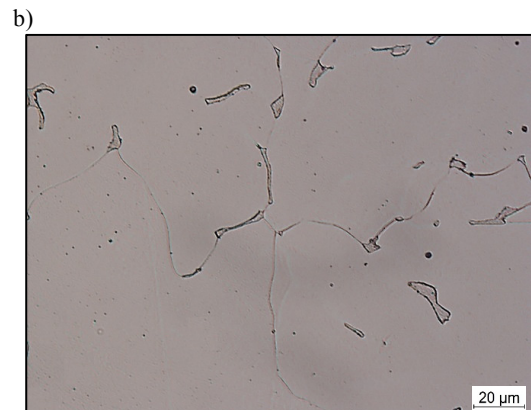
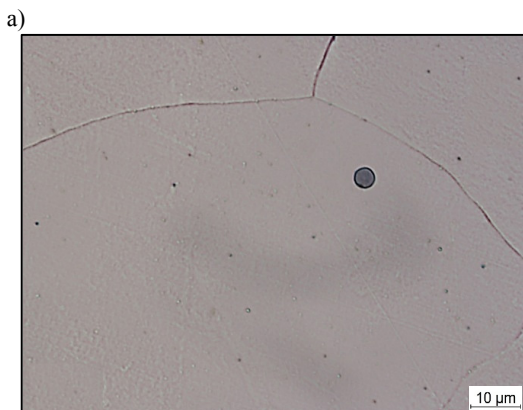
Fig. 1 (a÷c). Investigative stand

The load of the specimen was  $100\text{N}$ , its abrasion surface was  $263$   $\text{mm}^2$ , the rotation speed of the counter specimen was  $75$  rpm; the unit pressure was  $0.38$   $\text{N}/\text{mm}^2$ . The resistance to abrasion wear was tested using sand paper P40. The resistance to the adhesive wear when smeared was tested using CASTROL oil 10W40. The time of the test was  $480$  min in the cycle of  $16$  measurements,  $30$  min each. The mass decrease was determined within the accuracy of  $0.001$  g. Regarding the fact that the Department of Materials Engineering and Production Systems of the Technical University of Łódź (Poland) worked out new grades of austenitic and austenitic-ferritic cast steels which were applied to the UE patent the complete chemical composition of the cast steel subjected to wear tests was not given. The austenitic cast steel contained about  $0,04\%$  C;  $24,00\%$  Cr and  $10,00\%$  Ni; however, the “duplex” cast steel had the concentration of: C  $\approx 0,03\%$ ; Cr  $\approx 18,00\%$  i Ni  $\approx 7,00\%$ .

## 3. Research results

The microstructure of the tested austenitic cast steel is presented in Figure 2 (a÷c). It contained about  $10\%$  of ferrite.

Figure 3 (a÷c) presents the microstructure of “duplex” cast steel.



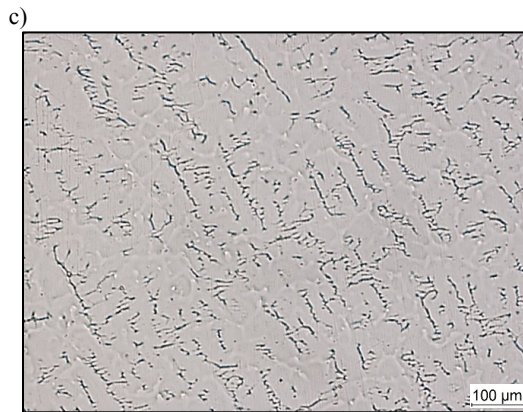


Fig. 2 (a+c). The microstructure of austenitic cast steel with a small amount of ferrite

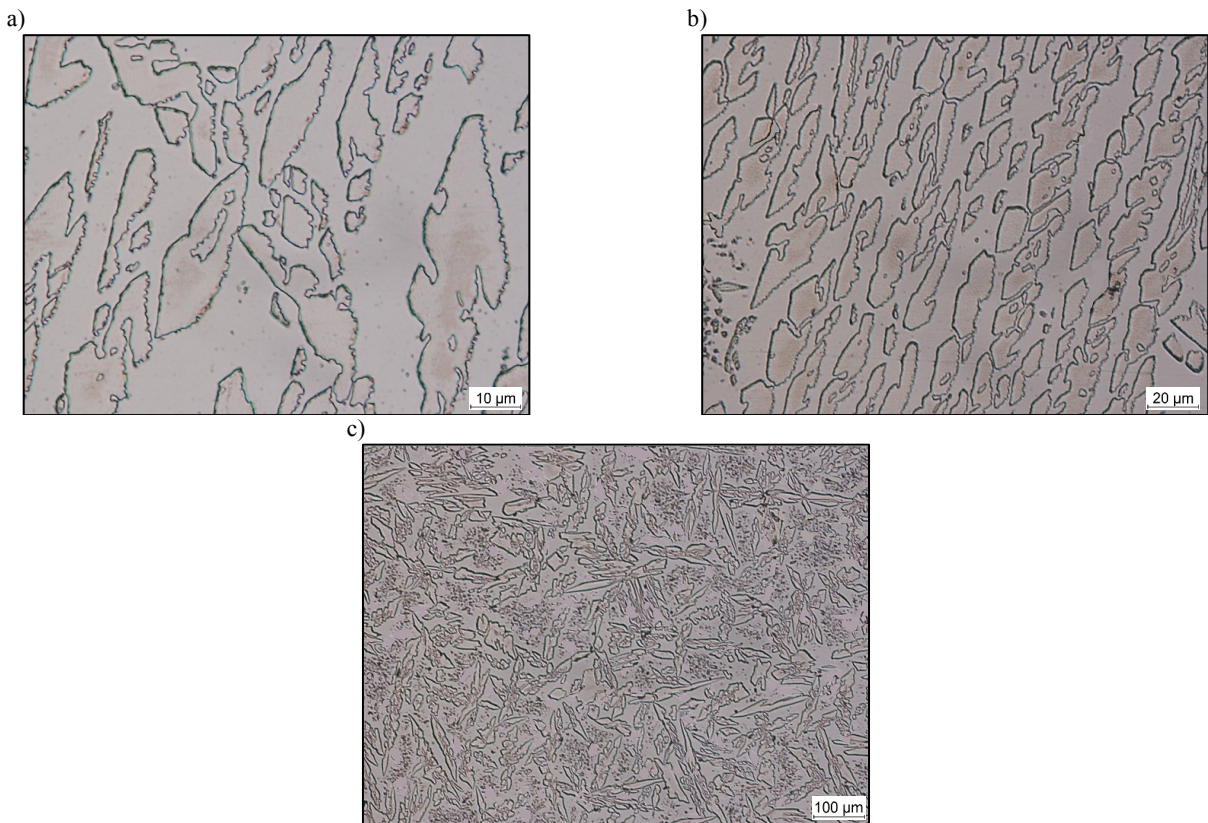


Fig. 3 (a-c). The microstructure of austenitic-ferritic cast steel containing about 60% of austenite and 40% of ferrite

The microstructure of the counter specimen made of steel C55 is shown in Figure 4 (a-h).

The abrasion wear curves of the tested cast steel grades are presented in Figure 5.

It follows from these that austenitic cast steel is more difficult to run in than “duplex” cast steel. After 2 h of treatment with sand paper, the “duplex” cast steel is characterized with a higher wear than the austenitic steel. However, the difference

in wear between the cast steels is not big. After 8 hours of treatment with sand paper, the wear of the austenitic steel was 1.559 g and that of the “duplex” was 1.679 g. The difference was 0.120g.

Figure 6 shows the curve of the change in adhesive wear without greasing of the tested cast steel and of the counter specimen made of hardened and low temperature tempered steel.

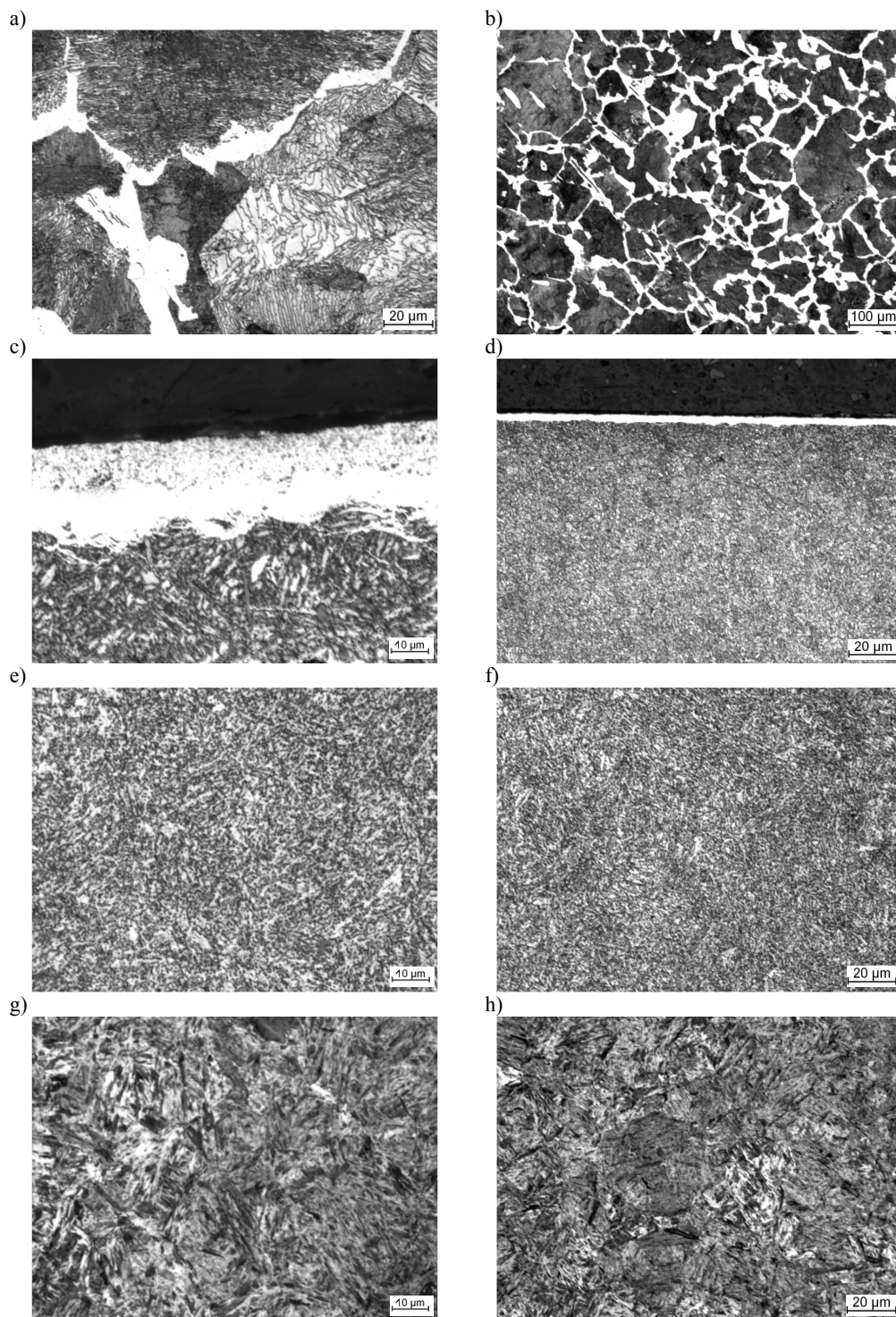


Fig. 4 (a-h). The microstructure of the counter specimen made of steel C55; a, b – after normalizing: pearlite, ferrite, non-metallic inclusions; c, d – after sulfonitriding: the sulfonitrided layer consists of the area of the external sulfuring which includes iron sulfides FeS and Fe<sub>2</sub>S, the area of the nitrogen compounds  $\epsilon$ ,  $\epsilon+\gamma'$ ;  $\gamma'$  and the area of tiny inclusions FeS in the phase  $\epsilon$ ; e, f – after nitriding: the area of the core: the mixture of troostite and sorbite, non-metallic inclusions; g, h – after hardening: low temperature tempered martensite, retained austenite, non-metallic inclusions

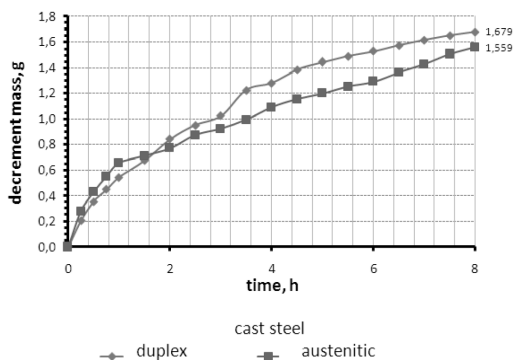


Fig. 5. The abrasion wear curves of the tested cast steel grades

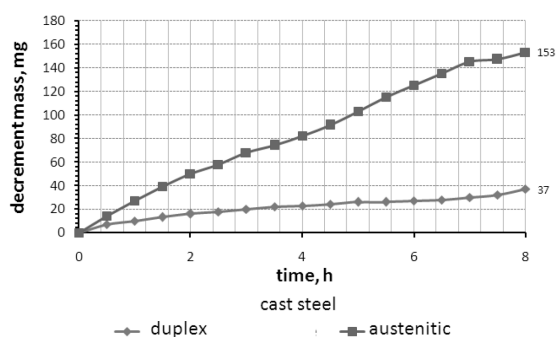


Fig. 6. The curves of the change in adhesive wear without greasing of the tested steel in cooperation with the counter specimen hardened and low temperature tempered.

In this case there was no run in period of the friction pair. There was no stick-slip either. The wear of the tested cast steel increased as the time of the experiment increased. The wear of the austenitic cast steel was much lower than that of the “duplex” cast steel, and after 8 h it was 37 mg against 153 mg of the “duplex”, i.e., 4 times higher. It should be supposed that it was caused by the austenite → martensite change and the deformation of the austenite as a result of twinning, which caused its strengthening.

The curves of the rubbing friction of the cast steel with the disc made of sulfonitrided C45 is shown in Figure 7.

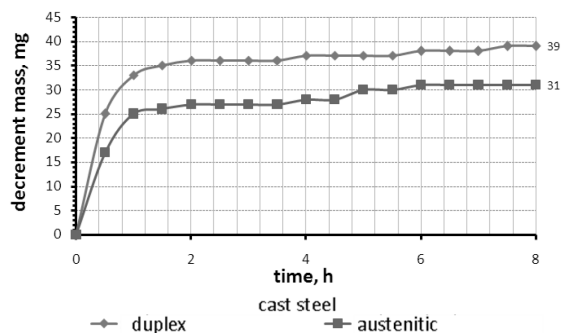


Fig. 7. The wear curves of the tested steel with the sulfonitrided counter specimen without oil greasing

In the case of this interaction there was a period of run in when the austenitic cast steel was subjected to intensive wear. The run in time was about 1.5 h. Then there was an insignificant mass decrease as the time passed by. After 8 h it was 8 h 39 mg for austenitic cast steel, and 31 mg for the “duplex” cast steel. The difference in the wear of the two grades of the cast steel was only 8 mg. During the experiment the stick-slip of the friction pair was not noticed. In this case the “duplex” cast steel decreased its wear about 5 times in comparison to the wear in interaction with the hardened steel. The intensity of the wear of the specimen was also smaller (Fig. 6).

Figure 8 presents the curves of the adhesive wear at rubbing friction of the tested cast steel with the counterpart made of normalized steel C55.

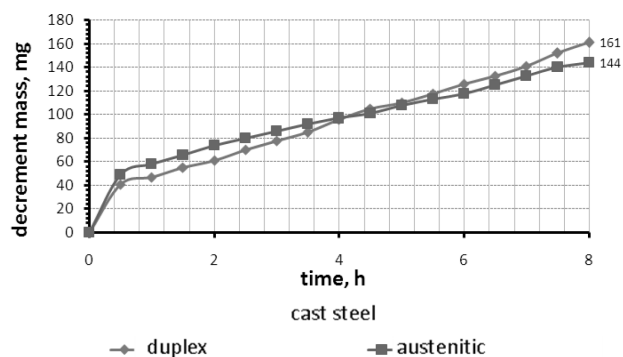


Fig. 8. Adhesive wear curves at rubbing friction of the tested cast steel with steel C45 after normalizing

It follows from it that like in the previous cases the friction couple was not subjected to the stick-slip. The period of run in of the two cast steel grades was about 1 h. For about 4 hours the higher wearing quality was shown by the austenitic cast steel. After that, the higher wearing quality was shown by the “duplex”, besides, the difference in the wear in both cast steel grades was not big and was 17 mg after 8 g of the cooperation (austenitic cast steel: wear 161 mg, “duplex” – 144 mg). The value of the wear was about 4.5 times higher in comparison to sulfonitrided counter specimen (Fig. 7).

In liquid friction using CASTROL oil, irrespective of the friction pair, the wear was very small and after 8 h test it was within the range of 1÷2 mg.

It follows from the presented data that in the two cases only the wear of the “duplex” cast steel was lower than that of the austenitic steel; that is, in the friction pair with the sulfonitrided and normalized counter specimen in rubbing friction, however, the microhardness of the austenite in the austenitic cast steel was 126 μHV0.1, and the microhardness of the austenite in the “duplex” cast steel was 226 μHV0.1 and of the ferrite it was 247 μHV0.1.

The obtained models of the regression of the wear curves of the tested friction pairs after the run in are presented in Table 1.

Table 1.

Comparison of the obtained models of the regression of the wear curves of the tested friction pairs after the run in

Type wear	Sort cast steel	Form model	Test F-Snedecora		R	R <sup>2</sup>	SEE	MAE
			F <sub>kr</sub>	F <sub>model</sub>				
Abrasion	duplex	power $y = 0.58217x^{0.457851}$	4.494	1486.76	0.9947	98.94%	0.050	0.033
	austenitic	second degree polynomial $y = 0.168623 - 0.370425x + 0.0231686x^2$	3.682	2565.29	-	99.71%	0.028	0.020
Adhesive on hardened disk	duplex	power $y = 26.3838x^{0.855855}$	4.600	5649.98	0.9988	99.75%	0.035	0.028
	austenitic	power $y = 10.4198x^{0.561729}$	4.600	1480.68	0.9953	99.06%	0.045	0.034
Adhesive on normalized disk	duplex	linear $y = 48.6548 + 11.9286x$	4.667	4180.13	0.9984	99.69%	1.544	1.270
	austenitic	linear $y = 30.019 + 16.1143x$	4.667	8810.90	0.9993	99.85%	1.436	1.181
Adhesive on sulfonitriding disk	duplex	exponential $y = e^{(3.21692+0.0306961x)}$	4.747	117.62	0.9526	90.74%	0.021	0.017
		linear $y = 24.7319 + 0.88516x$	4.747	117.56	0.9526	90.74%	0.615	0.485
	austenitic	exponential $y = e^{(3.54089+0.0150447x)}$	4.747	178.58	0.9680	93.70%	0.008	0.007
		linear $y = 34.4198 + 0.558242x$	4.747	176.59	0.9677	93.64%	0.317	0.258

It follows from it that the power function appears for the following friction pairs: abrasion – “duplex” and austenitic, adhesive rubbing friction: at hardened disc – “duplex” and austenitic. The quadratic function: abrasion wear – austenitic. The linear function for the pair: adhesive – “duplex” and austenitic and linear and exponential for the pair adhesive at the sulfonitrided disc.

The abrasion wear curves of the least resisting materials whose complete mass decrease is more than 4 gram in the 8h test are presented in Figure 9.

It follows from it that the least resistant to abrasion wear is gray cast iron EN-GJL-250. The most resistant to abrasion wear is spheroidal graphite iron of the EN-GJS-600-3 grade and spheroidal graphite iron of pearlitic with the ledeburitic carbides microstructure. The difference in the wear of both grades of spheroidal graphite iron is not big and is 0.57 g.

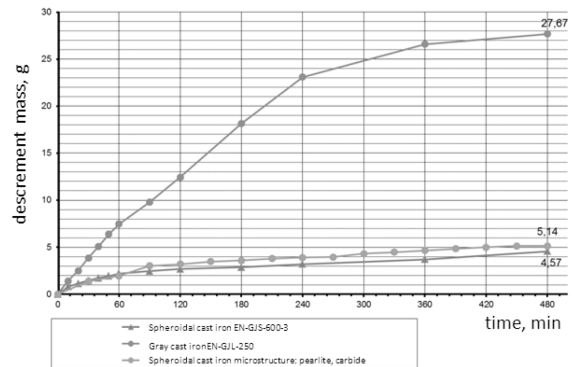


Fig. 9. The abrasion wear curves of the three least resistant materials

Figure 10 presents the materials with the highest degree of abrasion wear whose complete mass decrease was less than 2 grams.

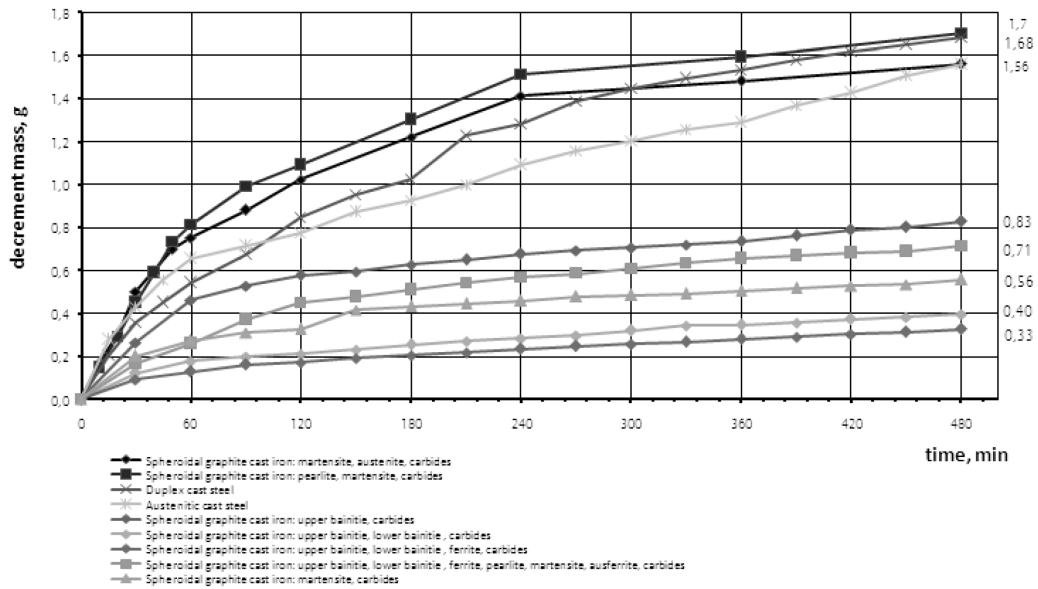


Fig. 10. The abrasion wear curves of the materials with the highest degree of abrasive wear resistance

It follows from the presented curves that the least resistant to abrasion wear material in this group is the spheroidal graphite pearlitic-martensitic iron with ledeburitic carbides (after 8 h the mass decrease was 1.70 g) and the “duplex” cast steel (after 8 h the mass decrease was 1.68 g). The most resistant to the abrasion wear was the spheroidal graphite iron with the mixture of bainites and ledeburitic carbides (after 8 h the mass decrease was in the range of 0.33÷0.40 g). The tested materials can be divided into two groups. In the first group the final wear was within the range of 1.56÷1.70 g and it includes: spheroidal graphite pearlitic-martensitic and martensitic-austenitic cast iron; both with carbides and cast steel: austenitic and “duplex”.

In the second group the final wear was within the range of 0.33÷0.83 g and it includes spheroidal graphite cast iron with ledeburitic carbides and the microstructure of the metallic base which consists of: upper bainite, a mixture of bainites, pearlite, martensite and ausferrite, and also martensite. The abrasion wear of this group of materials is about 2÷5 times lower than in the first group of materials. Austenitic cast steel and “duplex” are in the first group of materials.

The adhesive rubbing wear curves of the materials which make the friction pair made of normalized steel C55 are shown in Figure 11.

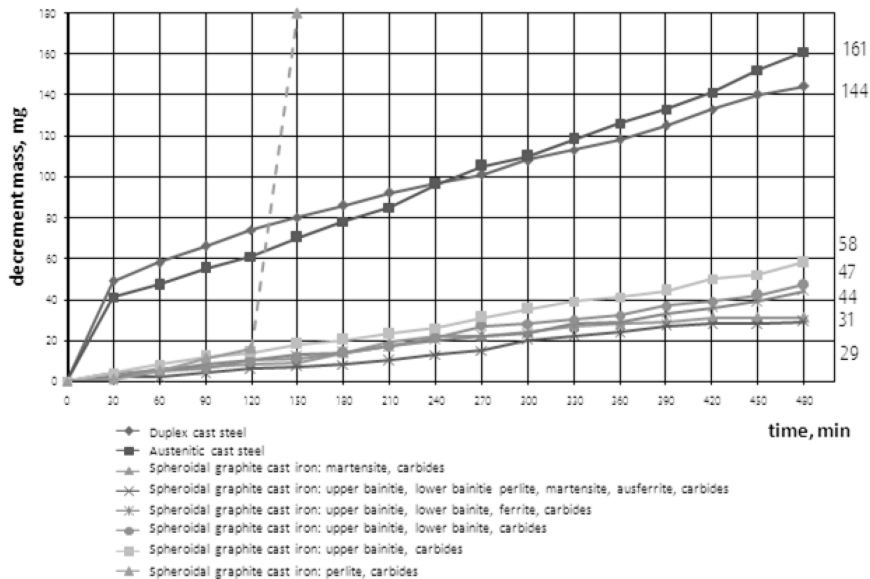


Fig. 11. The adhesive rubbing wear curves of the friction pair with the counter specimen made of normalized steel C55

It follows from the graph that the austenitic cast steel and the „duplex” are far less resistant to wear than the spheroidal graphite iron with bainitic or martensitic with ledeburitic carbides microstructure. The complete mass decrease of the both grades of cast steel is about 5 times more than that of the most resistant spheroidal graphite cast iron with the microstructure of bainites and pearlite, martensite and ausferrite

with carbides. The specimen from spheroidal graphite pearlitic with carbides cast iron after 2 h is subjected to destruction (the dash line in the graph). It is typical that spheroidal graphite cast iron did not show the period of the run in unlike the tested cast steel.

Figure 12 presents the adhesive rubbing wear curves of the tested material in interaction with hardened steel C55.

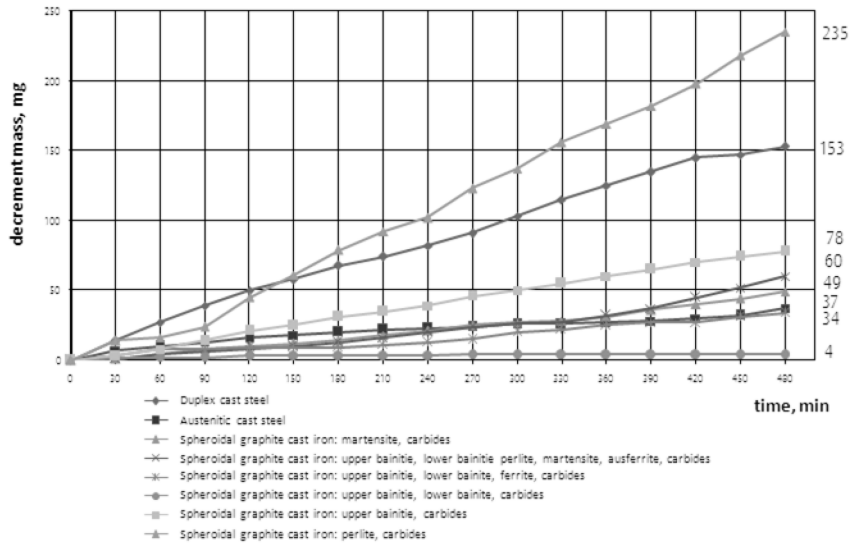


Fig. 12. The adhesive rubbing wear curves of the tested materials interaction with hardened steel C55

In this case the highest degree of wear (235 mg) was typical of the spheroidal graphite pearlitic with carbides cast iron. Lower wear (153 mg) was shown by the “duplex” cast steel. The lowest wear (4 mg) was shown by spheroidal bainitic with carbides cast iron. Relatively low wear (37 mg) was shown by the austenitic cast steel. Also the cast steel of the microstructure

of upper bainite with carbides showed relatively low wear (78 mg).

The adhesive rubbing wear curves of the friction pair of the tested materials with the C55 counter specimen after sulfonitriding is presented in Figure 13.

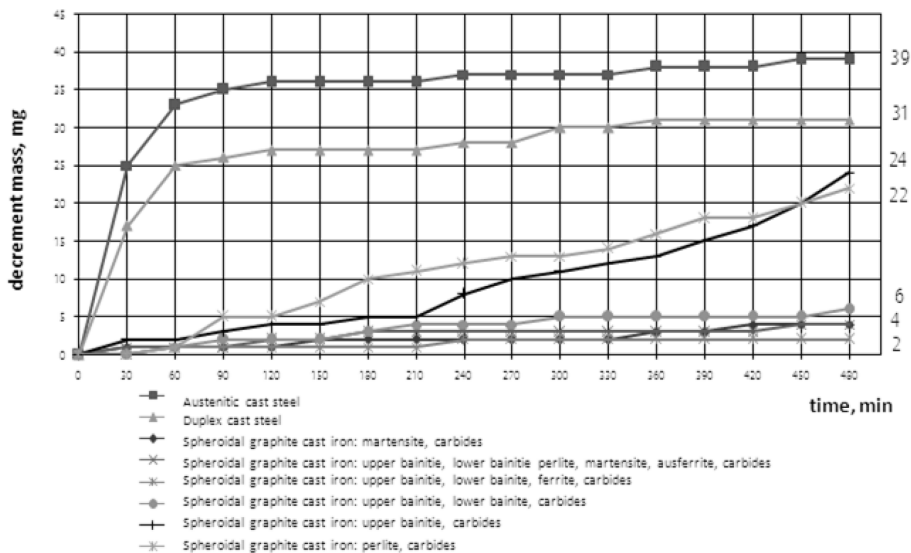


Fig. 13. The adhesive rubbing wear curves of the friction pair of the tested materials with the counter specimen made of C55 steel



It follows from the presented data that the austenitic cast steel and the “duplex” had the highest wear. The next in line was the spheroidal graphite pearlitic and upper bainitic with the carbides cast iron.

## 4. Conclusions

The conclusions which follow from the presented research results are as follows:

- austenitic cast steel and austenitic-ferritic cast steel show similar abrasion and adhesive rubbing wear when interacting with normalized, hardened and sulfonitrided steel C55;
- the lowest mass decrease was demonstrated by cast steel during interaction with sulfonitrided steel;
- the wear curves of the cast steel after the period of run in can be described by the mathematic function with the regression ratio in the range of  $R^2 = 0.91 \div 0.99$ ;
- for different friction pairs the regression ratio can be: a power function, a quadratic function, a linear function and an exponential function;
- austenitic and austenitic-ferritic cast steel in different combinations of the friction pairs has a higher wearing quality than gray cast iron EN-GJL-250 and spheroidal graphite cast iron EN-GJS-600-3;
- austenitic and austenitic-ferritic cast steel in different combinations of the friction pairs is characterized by a much lower wearing quality than spheroidal graphite cast iron with ledeburitic carbides with the microstructure of a metal matrix from the upper bainite, mixture of upper and lower bainite, mixture of pearlite, bainites, ausferrites and martensite as well as martensite with austenite;
- in the adhesive wear test using the CASTROL oil the tested cast steels and cast iron showed a small mass decrease within the range of  $1 \div 2$  mg.

Generally, it should be said that the basic function of austenitic and austenitic-ferritic cast steel is ensuring a very long resistance to corrosion in different environments and excellent welding properties. Resistance to abrasion and adhesive wear is required in the second place for the components used in specific working conditions. The combination of high resistance to corrosion with high wearing quality, as follows from the presented research results, is relatively difficult. The comparative analyses of the wearing quality of austenitic cast steel and “duplex” were carried out for spheroidal graphite cast iron with the microstructure the most resistant to wear. In connection with this, the wearing quality of cast steel in comparison to cast iron was not discreditable if the numeric values of the mass decrease are compared. The presented research results are the beginning for further design of new grades of austenitic and “duplex” cast steel with a more beneficial wearing quality than that shown in this work.

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