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Usage of abrasion-resistant materials in agriculture

Využití otěruvzdorných materiálů v zemědělství

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Abstract

Agricultural soil-processing machines are subject to an extensive abrasive wear. This paper analyses technical materials and their fitness to exchangeable parts of plough bottoms, such as edge-tools and whole plough cutting edges. There were tested abrasion-resistant steels with different microstructures: austenite, martensite-bainite, and carbide. Steel with the pearlite-ferrite structure was used as an etalon. Abrasion resistance tests were processed in compliance with the norm ČSN 01 5084, which is a test of abrasion wear on abrasive cloth.

Keywords: abrasive-resistant steel, abrasive wear, agriculture, microhardness, structure, soil management

Abstrakt

Zemědělské stroje pro zpracování půdy jsou zatíženy značným abrazivním opotřebením. Předložený příspěvek analyzuje vhodnost technických materiálů pro výrobu vyměnitelných částí plužního tělesa. Jedná se především o dláta i celé plužní ostří. K testům byly zvoleny otěruvzdorné materiály s rozdílnou mikrostrukturou. Jednalo se o kategorie ocelí s mikrostrukturou austenitickou, martenziticko-bainitickou a karbidickou. Jako etalon byla použita ocel se strukturou perliticko-feritickou. Testy abrazivní odolnosti byly provedeny dle ČSN 01 5084. Jedná se o test abrazivního opotřebení na brusném plátně.

Klíčová slova: abrazivní opotřebení, mikrotvrdost, otěruvzdorná ocel, struktura, zemědělství, zpracování půdy

Detailní abstrakt

Vlivem opotřebení strojních součástí dochází k odstávce celého stroje nebo dokonce celé výrobní linky. Jednou z oblastí, kde nastává masivní opotřebení, je zpracování půdy. Abrazivní opotřebení lze tedy definovat jako nežádoucí změnu povrchu nebo rozměrů tuhých těles, způsobenou buď vzájemným působením funkčních povrchů, nebo funkčního povrchu a abrazivního media.

Cílem předloženého příspěvku je otestovat vhodnost několika technických otěruvzdorných materiálů pro použití a výrobu funkčních částí zemědělských strojů na zpracování půdy. Jedná se o materiály s rozdílnou vnitřní strukturou i mechanickými vlastnostmi. Jako porovnávací etalon byla zvolna ocel 12 050. V počáteční fázi identifikace jednotlivých materiálů byla změřena jejich tvrdost dle ČSN EN 23878 (metoda dle Vickerse. Následovala analýza vnitřních strukturních fází jednotlivých materiálů. Dle metalografických výbrusů byly zjištěny nehomogenity v oceli 12 050. Na připravených metalografických preparátech bylo provedeno rovněž měření mikrotvrdosti jednotlivých strukturních fází. Dle provedených testů lze konstatovat korelaci mezi tvrdostí, základní strukturou i mikrotvrdostí zkoušených vzorků.

Pro analýzu abrazivního opotřebení byla zvolena zkouška dle ČSN 01 5084. Jedná se o stanovení odolnosti kovových materiálů proti abrazivnímu opotřebení na přístroji s brusným plátnem. Toto zařízení bylo zvoleno z důvodu zachování konstantních podmínek během zkoušky. U zařízení s volnými částicemi dochází při delším časovém intervalu trvání zkoušky ke značné degradaci používaného abrazivního média.

Z výsledků jednotlivých analýz je v závěru publikace predikována vhodnost testovaných materiálů pro použití na výrobu vyměnitelných funkčních částí zemědělských strojů, které přichází do přímého kontaktu s půdou.

Introduction

Wear is an undesirable change of surface or size of solids, which is cause either by mutual interaction of functional surfaces or by a functional surface and a medium. The trend is to use materials which are resistant to both abrasion and other degradation forces, such as corrosion or mechanical fatigue. There are technical materials with middle hardness and high tenacity (Blaškovič, et al, 1990, Suchánek, et al, 2007).

Considerable weight losses caused by abrasion wear can be observed in functional parts of soil-processing machines. Massive losses can be eliminated by laser deposition (Daňko, et al, 2011). However, the deposited material may increase the reluctivity of the whole system. The sence of abrasive wear of soil-processing tools is production of microchipping from the surface of functional tool. The size of the microchipping is dependent on many factors, mostly microstructure of the base material, sharpness of abrassive particles and humidity of the abrading agent (Vysočanská, et al., 2012).

Abrasive wear in agriculture is also observed at tools which do not belong to the soil-processing machines, such as drill coulters, active or pasive elements of beet lifters, etc. Working life of these tools can be prolonged by a well-selected base material or using hardmetal weld deposits (Čičo, et al., 2011a; Dushyant et al., 2010; Lechner and McColly, 1959). Nevertheless, the disadvantage of hardmetal coatings is a significant mixture of welded metal with base material and also heat-affected area in the neighbourhood of the weld bead.

Material and Methods

In the soil processing abrasion wear has the biggest influence on degradation of machine parts. They are mostly parts which are directly affected by the soil (Kotus, et al., 2011a, Čičo, et al., 2011b). Materials used for production of tools which come into a direct contact with abrasive particles, can be put into the category of abrasion-resistant steels. The fitness of technical materials for production of soil-processing tools can be tested by different ways. There are tests with fixed or free abrading agents or apparatus with a layer of free abrading agents between bearing surfaces. The test used for this paper was test with fixed abrading agents according to the norm ČSN 01 5084, it is an abrasive cloth test. Tested materials were selected with reference to their usage not only in agriculture, but also in building and transport industries.

Characteristics of tested materials

Steel 12 050: this material is being mostly used for extensively stressed machine parts and dynamically stressed components. After an appropriate heat-treatment the material performs a good tenacity. Chemical composition of this material is showed in Table 1.

Table 1: Chemical composition of steel 12 050

Name according to the ČSN norm	Chemical composition [%]								
	C	Mn	Si	Cr	Mo	V	W	Ni	Oth.
Steel 12 050	0.42	0.50	0.17	0.25	-	-	-	0.30	-

Samples made of the steel 12 050 were used as etalons. From this reason, the samples were not heat treated, so the base structure was formed by ferrite and pearlite.

Creusabro 4 800: this material is mostly used for renovation of abrasive worn machine parts. It is also used in mining. It is a material with a content of residual austenite, which is subsequently able to transfer itself (due to strains or pressure) to secondary martensite.

Table 2: Chemical composition of steel Creusabro 4 800

Creusabro 4 800	Chemical composition [%]											
	C	Mn	Si	Cr	Mo	V	W	Ni	P	Cu	Al	Ti	Oth.
	0.19	1.50	0.33	1.55	1.16	-	-	0.28	0.08	0.09	0.02	0.05	-

Creusabro M: It is abrasive-resistant manganese steel, resistant to dynamic abrasive wear. This steel is used mostly for equipments which require a high resistance to wear in the form of strong shocks, such as crushing boards or sheeting of air-blast machine.

Table 3: Chemical composition of steel Creusabro M

Creusabro M	Chemical composition [%]												
	C	Mn	Si	Cr	Mo	V	W	S	P	Cu	Al	Ti	Oth.
	1.10	13.0	1.0	-	-	-	-	max 0.0002	max 0.002	-	-	-	-

Setudor 204: it is a high-solidity material used for bladings of projectile wheels of air-blast machines. Samples were gained directly from the manufacturer without the possibility to identify their chemical composition. Structure of the material is composed by tungsten carbide stored in a basic metal matrix.

Results and Discussion

Measurement of hardness of tested samples according to the national standard ČSN EN 23878

Hardness is being defined as material resistance towards penetration of foreign matters. In order to achieve minimal roughness of cutting surface of samples for hardness measurement were prepared on metallographic saw Mikron 110. In order to accurately measure lengths of diagonals of diamond pyramid pressed into the sample, the sample surface has to be straight and smooth. (Pošta, et al., 2002)

Measurement of tested samples was processed according to Vickers. A diamond pyramid with the apex angle of 136 ° was pressed into the sample. Load pressure for this sample was 98.1 N (HV10) for 10 s. Measurement was processed on five places and an average hardness was calculated. Measured values as well as the average value are recorded in Table 4.

Table 4: Hardness HV of the samples

Tested materials	Measurement					Average hardness [HV_{10}]
	1 [HV_{10}]	2 [HV_{10}]	3 [HV_{10}]	4 [HV_{10}]	5 [HV_{10}]	
Etalon 12 050	154	158	155	153	157	**155.4**
Creusabro 4 800	425	426	421	425	423	**424.0**
Creusabro M	274	276	274	274	275	**274.4**
Setudor 204	819	819	822	824	817	**820.2**

Microstructure of tested materials

Mechanical characteristics of any material are influenced by its inside microstructure. In order to analyze the inner structure, metallographic samples were prepared.

The goal of the metallographic observation is to assess the quality of analyzed steel, especially purity and content of structure elements after heat treatment. Metallographic microscope Neophot 21 was used for this analysis, magnification of 800 times was used for Figs. 1–4. Afterwards, metallographic specimens were used also for microhardness measurements.

Purity of the material 12 050 is not on a high level. Metallographic analysis has found sulphides and oxides coming from the production process in this material. As it is apparent in Figure 1, the structure of untreated steel is formed by a mixture of ferrite and pearlite.

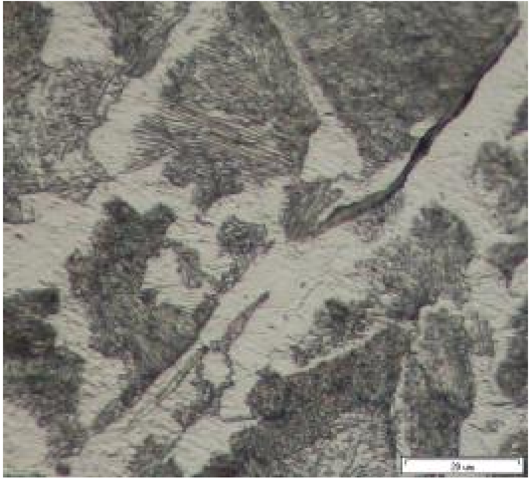

Figure 1: Steel 12 050 without heat treatment

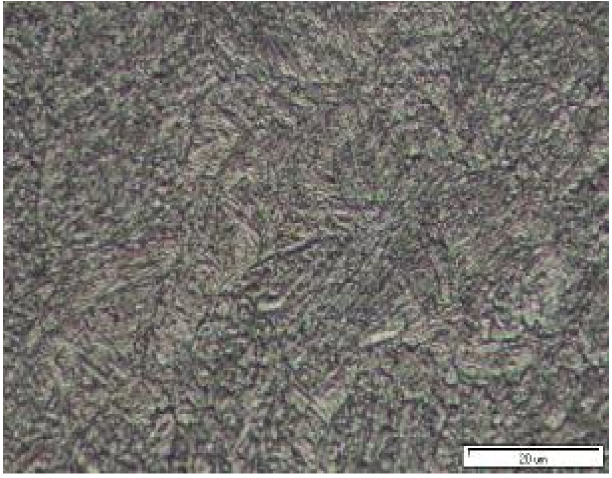

Figure 2: Abrasion-resistant steel Creusabro 4800

Abrasion-resistant steel Creusabro 4800 performs much better characteristics. There were no sulphides found in all of the metallographic samples; the structure is formed by a mixture of bainite- martensite needles, see Figure 2. This material has a high ability of deformation hardening, which is used in abrasive wear. On one hand the presence of carbides Cr + Mo + Ti increase the Microhardness; on the other hand, carbides may be broken out of the basic matrix. (Čičo, et al., 2011c, Bednář, et al., 2012)

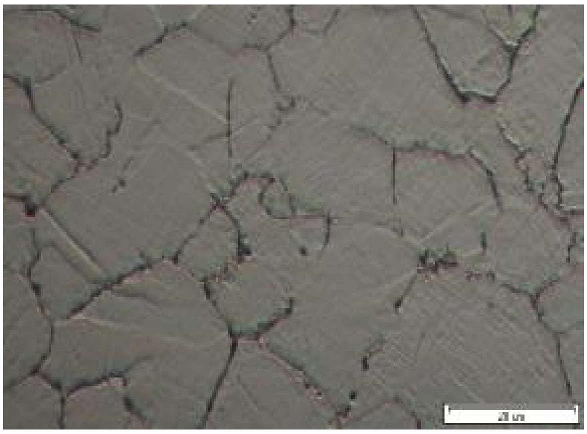

Figure 3: Creusabro M

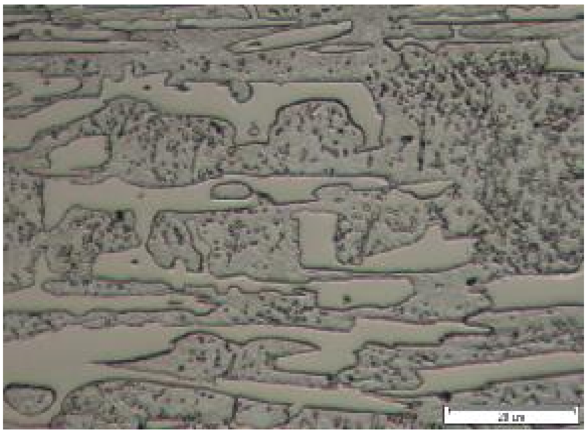

Figure 4: Setudor 204

Stainless steels class 17 can be divided into three categories; there are austenite, martensite and ferritic steels. For the experiment austenite steel, whose structure is formed by austenite only and carbides at grain borders (see Figure 3), was chosen. It is manganese steel, which is also called Hadfield steel. In order to show carbides, it is necessary to use an electron microscope. This material is characterized by excellent hardening characteristics at severe concussions.

Figure 4 shows metallographic scratch pattern of material Setudor 204, which is characteristic by lines of carbides stored in the basic metal matrix.

Microhardness according to the national standard ČSN EN ISO 6507-1

Microhardness was measured with Hanneman microhardness device, which is a part of a metallographic microscope Neophot 21, using a standard Vickers method. A diamond-tipped cone of 136° using the force of 0.9806 N is indented into the material.

The measurement was undertaken using three samples for each individual steel and an average was counted and recorded in Table 5.

Table 5: Microhardness of the individual structural phases

Used steel	Ferrite [HV]	Pearlite [HV]	Bainite + Martensite [HV]	Austenite [HV]	Carbides [HV]
Etalon 12 050	190	242	–	–	–
Creusabro 4 800	–	–	464	–	–
Creusabro M	–	–	–	161	–
Setudor 204	–	–	–	–	1,376

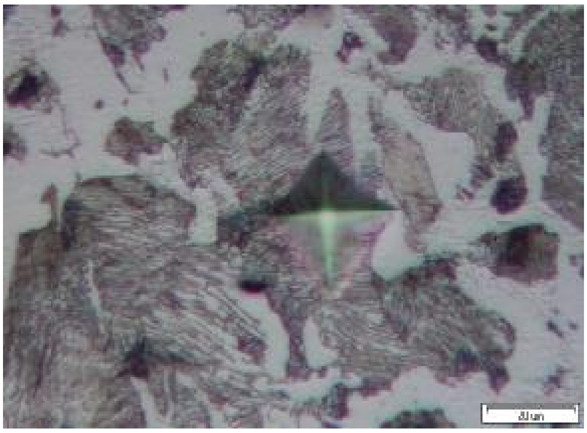

Figure 5: Steel 12 050

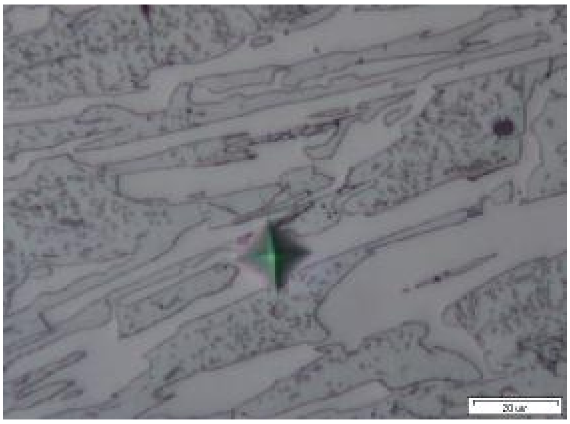

Figure 6: Setudor 204

Results of measured microhardness values according to Hanneman correlate with macrohardness of measured samples. As is apparent from Figure 5, steel 12 050 is formed by pearlite-ferrite structure with a high pearlite lamella dispersity. At the same magnification of both of the microstructures (500 times), a double length of impress of the testing pyramid is apparent, compare Figs. 5 and 6.

Wear testing according to the national standard ČSN 01 5084

The laboratory testing of the wear on abrasive cloth is based on the norm ČSN 01 5084 (see Figure 7). The tested sample is held in a holder and pressed by a weight to the abrasive cloth. During the testing, the horizontal disk with the abrasive cloth is rotated and the tested body is moved from the centre to the edging of the abrasive cloth. After the given length of the wearing course, the terminal switch will stop the machine. The specimens are cleaned and the weight decrease determined by weighing, see Fig. 8.

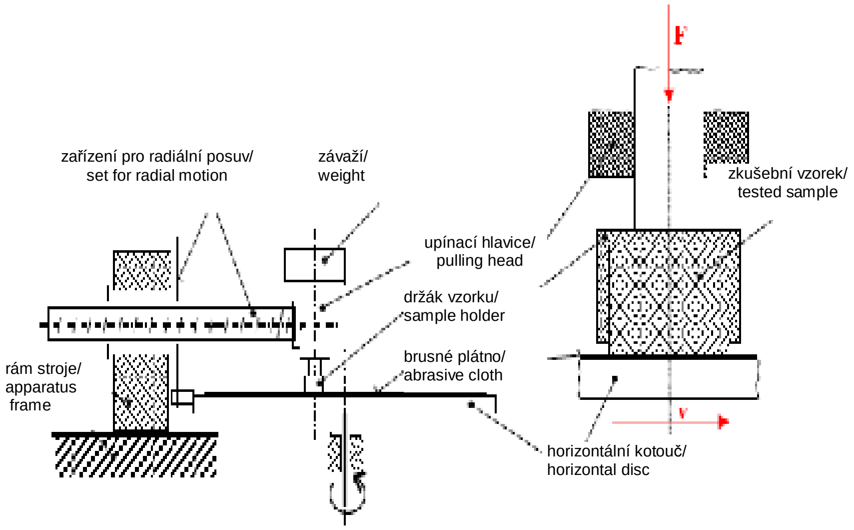

Figure 7: Equipment used for determination of abrasive tolerance of technical materials (Votava, 2012)

Proportional resistance against wear F was set according to relation:

$$\Phi_m = \frac{m_{et}}{m_{vzo}}$$

where: m_{et} – etalon weight decrease [g] m_{vzo} – specimen weight decrease [g]

Conditions of the laboratory test:

- form of the testing specimen: cube 10 × 10 × 10 mm,
- sample number of each tested material: 3,
- comparing etalon: untreated steel 12 050,
- length of the friction course: 250 m,
- diameter of the revolving disc: 480 mm,
- max. sliding speed of the tested body: 0.5 m×s^{-1},
- specific pressure: 0.32 N×mm^{-2},
- radial motion of the tested body: 3 mm×turns^{-1},
- abrasive cloth: corundum, granularity 120.

There were created 3 series of tested materials and weight losses were measured, which are depicted in Figure 8. Individual samples were prepared on metallographic saw using the method of accurate cutting. Important factor when preparing samples was to guarantee optimal cooling of the sample. Maximal removal of heat from the cut place eliminates heat affected area, which could result in weight losses in the first measurement.

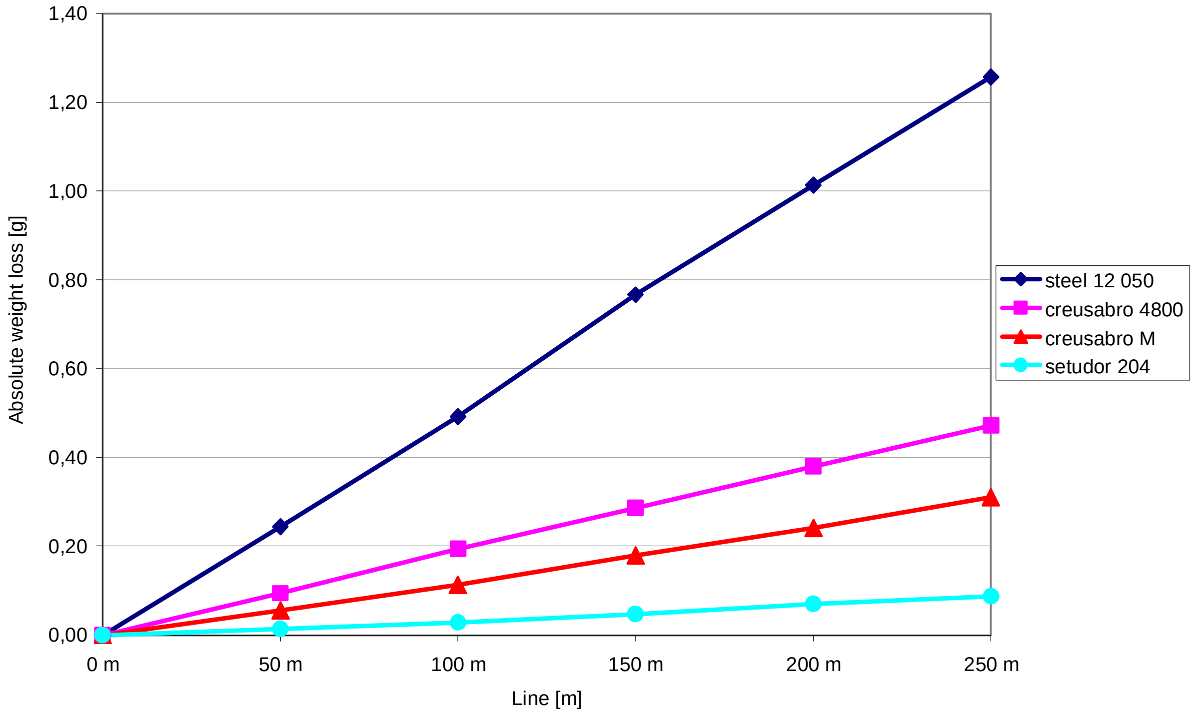

Figure 8: Weight losses of tested materials

Figure 8 shows weight losses of tested samples after each 50 metres on abrasive cloth. As the test is processed under constant conditions, weight losses of the base material are almost linear.

Laboratory tests of abrasive wear have a considerable predicative ability when comparing wear of a particular group of tested materials. As the testing conditions are strictly defined, only one particular effort, that is wear, is guaranteed. (Kotus, et al., 2011b). However, in normal technical operation a combination of more wear types appears at the same time, that is mainly a combination of abrasive and erosive wear.

One of the crucial factors influencing abrasive resistance is its hardness. However, it is necessary to take into consideration also the chemical composition of the steel and its heat treatment. (Votava, et al., 2007, Stodola, et al., 2008)

Processed tests have evidently proved a low abrasive resistance of steel 12 050. This steel was used as an etalon to which other values were compared. Microhardness is only around 200 HV, and the microstructure is formed by a mixture of ferrite and pearlite. Wear of the sample after 250 metres was 1.257 g. Even though the steel contains only 0.42 % of carbon, it is not advisable to use this material in operations with an enormous abrasive stress.

Hardness of steel Creusabro 4800 was 2.7 times higher than hardness of the etalon, this bainite-martensite structure had harness of 460 HV.

Austenite steel Creusabro M showed only 1.6 times higher hardness than the base etalon. The resistance to abrasive wear was 4 times higher comparing to the steel 12 050. Measured values Microhardness values of the structure were around 160 HV. This material shows significant hardening when abrasive elements attack.

The last tested material was steel Setudor 204. This material is formed by carbide particles which are put in a metal matrix. Macrohardness of this material was 5.2 times higher than the etalon; however, the abrasive-resistance was 16.2 times better than by the etalon. Hardness of the extracted carbides in the base microstructure reached 1 376 HV.

Materials were tested on abrasive cloth in compliance with the norm ČSN 01 5084. Based on the results of this test, there is defined an abrasive-resistance under static conditions. Before applying the results to the technical operations, there should be processed also tests of dynamic characteristics. Low impact resistance lowers the applicability of the materials.

Conclusions

Soil-processing machines are irreplaceable in agriculture. Abrasive wear and abrasive wear accompanied by force stresses have the biggest negative influence on degradation of these machines. It is thus necessary to use such material which has a good abrasive resistance and a good ductility as during the soil cultivation the soil processing machine parts are subjected to extensive strains. Abrasive wear is also influenced by soil characteristics (its chemical composition, moisture and cementation).

One of the possibilities to eliminate negative abrasive wear is to select an appropriate material for the soil processing parts: manganese austenite steel (Creusabro M) is cold formed and reaches a good hardening of the given part. Hardness is increased when the metastabile austenite is being transferred on martensite during the process of plastic deformation. The steel performs a good wear resistance at extensive surface stress which occurs mainly in ploughing. However, this steel is not magnetic and a possible loss of working part may cause problems to some crop machines, which have security mechanisms (cutting mechanisms of forage harvesters) based on the principle of magnetic characteristics of common steels.

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