Application of ductile iron in the manufacture of ploughshares

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ABSTRACT: The service life and reliability of machines for basic soil cultivation is mainly affected by abrasive wear. The working tools of these machines are mostly made of steel. The paper deals with the possibility of manufacturing ploughshares and reversible points of austempered ductile iron (ADI). The authors examine the abrasion resistance of ADI working tools and compare it with that of the material applied by a leading world manufacturer of ploughshares. Using an appropriate mode of the heat treatment of ADI, abrasion resistance comparable to that of the original tools can be obtained.

Keywords: abrasive wear; ploughshares; ductile iron; austempering

Ploughing conditions often cause excessive wear of agricultural machine parts. The principal cause of the high degree of wear in ploughshares are the hard particles contained in the soil, in particular SiO_2 in quartz sand, whose hardness reaches 900 to 1,280 HV. However, in view of the complicated dynamic stressing involved in ploughing it is necessary to manufacture ploughshares of steels of medium strength and higher toughness (HORÁČEK 1999). High-grade carbon steels 12,060 used to be employed in the manufacture of ploughshares. Today, ploughshares are used that are cast of high-strength wear-resistant steel low-alloyed with chromium, molybdenum, nickel, and tungsten (denoted as VPH), and also forged ploughshares of high-grade steel 13,340.6, which is low-alloyed with manganese and silicon (HORÁČEK 2001).

The ploughshares made by leading manufacturers of soil cultivation machines (Möllbro, Kverneland, Lemken) exhibit very good properties but their purchase cost is a disadvantage. Ways are therefore sought how to increase the service life of worn parts, for example by renovation (forging, application of martensitic, austenitic, ledeburitic, and carbidic coatings, welding-on steel plates face-hardened with sintered carbides, e.g. Castodur Diamond Plates – CDP, etc.).

Last but not least, new materials for and technological processes of manufacturing machine parts are sought. Ploughshares are mostly made of steel; the present authors have met with cast iron being used in these cases only seldom (BŘEZINA, BROŽEK 1993).

Common pearlitic cast irons exhibit considerable natural resistance to wear. Quenching will increase the resistance to abrasion as the pearlitic matrix is replaced with martensite and retained austenite. Further increase in hardness can be obtained by alloying, when special hard carbides (e.g. complex carbides of chromium or still harder carbides of vanadium) become part of the carbidic eutectic. Alloyed heat-treated white cast irons rank with the most resistant cast structural materials in conditions of abrasive wear but due to their insufficient strength and toughness they are not employed for ploughing.

Graphitic cast irons that come into consideration in this context are the ductile irons (cast irons with spheroidal graphite). With austempered ductile irons a structure with extraordinary hardness, toughness and wear resistance can be obtained (Table 1).

The structure of ductile iron before heat treatment is formed by spheroidal graphite and a matrix of varied ferrite-to-pearlite ratio. Austempering consists in heating the ductile iron in a salt bath to temperatures of 850–950°C. When austenitic structure has been obtained, the component is quickly transferred into another salt bath of 230–450°C. The minimum holding time at this temperature is limited by the time when the ferritic-austenitic structure is obtained, while the maximum holding time is limited by the time when austenite in the austenitic-ferritic structure begins to decompose into ferrite and carbides. The resultant structure is austenitic-ferritic (ausferrite) with a small amount of martensite or carbides (PLACHÝ et al. 1997). The state of the structure before heat treatment and after austempering is given in Fig. 1.

If the casting is exposed to surface hardening (shot-peening, ball milling), austenite is transformed, and substantial pressure stresses develop in the surface layer, which increase the resistance of the component to both fatigue failure and abrasive wear.

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Table 1. Standardized ADI qualities according to EN and ASTM

Mark	Rm (MPa)	$Rp_{0.2}$ (MPa)	A* (%)	Hardness HB	KV** (J)
EN-GJS-800-8	800	500	8	260–320	
ASTM 897 Grade 1	850	550	10	269–321	100
EN-GJS-1000-5	1,000	700	5	300–360	
ASTM 897 Grade 2	1,050	700	7	302–363	80
EN-GJS-1200-2	1,200	850	2	340–440	
ASTM 897 Grade 3	1,200	850	4	341–480	60
EN-GJS-1400-1	1,400	1,100	1	380–480	
ASTM 897 Grade 4	1,400	1,100	1	388–477	35
ASTM 897 Grade 5	1,600	1,300	–	444–555	

* Ductility in EN A_5, in ASTM A_4
** Impact energy values are for specimens without notches

The aim of the present paper is to test abrasive wear resistance in working tools made of austempered ductile iron and compare it with that of original tools manufactured by the Kverneland Company.

MATERIALS AND METHODS

Abrasive wear resistance of working tools made of ADI was tested by the comparative method, using the original tools of Kverneland Company. The value of wear was established in field and laboratory tests on the basis of mass decrements.

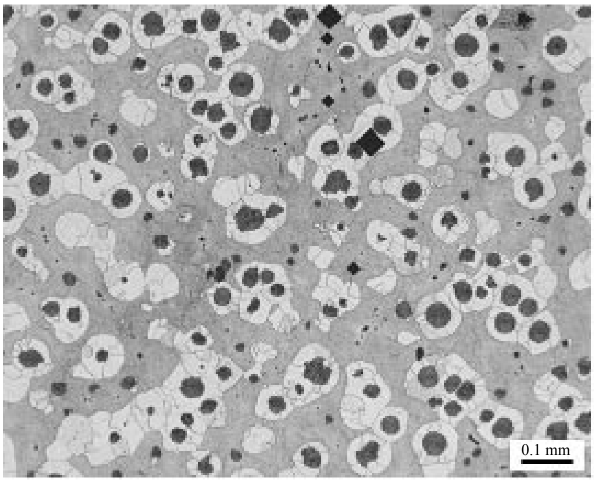
Test equipment

In the field tests, a JOHN DEERE 6620 tractor with radar was used in combination with a Kverneland ES 95 4r mounted four-furrow reversible plough (Fig. 2). The measurement was conducted on sabulous clay soils near the town Namest nad Oslavou in autumn 2003.

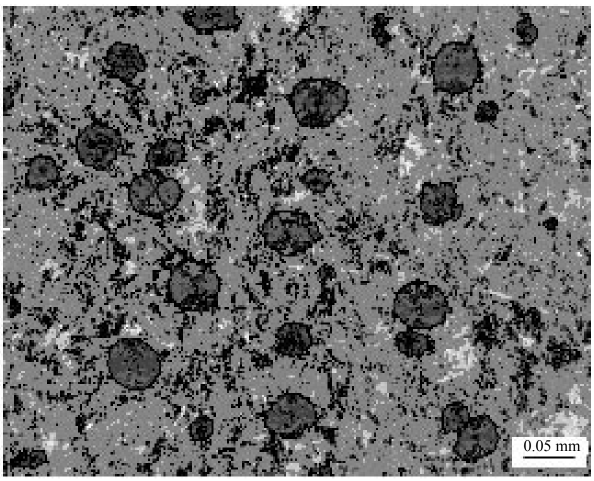
Laboratory abrasive-cloth tests of wear resistance complied with the ČSN 01 5084 Standard (Fig. 3). In the test, the test specimen is pushed by a weight onto emery abrasive cloth at a specific pressure of 0.32 MPa. Instead of grade 12,014 steel, a specimen taken from the original Kverneland ploughshare was used as reference standard. Volume losses on a friction track of 150 m in length were compared for specimens of the materials under testing.

Test specimens

In the tests of abrasive wear resistance the following test specimens were used:
– field ploughing tests:
  – ploughshares



Before heat treatment



After austempering

Fig.1. The structure of ductile iron

Fig. 2. JOHN DEERE 6620 tractor combined with Kverneland plough

– reversible points
– comparative plates 80 × 80 × 8 mm, with a dia. 10 mm opening, recessed for a bolt with conic countersunk head
– laboratory abrasive-cloth tests:
– test cubes 10 × 10 × 10 mm.

All the test specimens were made of two types of material:
– wrought steel of the original Kverneland (HRC 49) working tools
– two variants of austempered ductile iron (ADI):
– 880/380/2h
– 880/200/2h.

Comparative steel plates and cubes were cut (under intensive cooling) from an original Kverneland ploughshare.

The other material used was ductile iron, from which ploughshares, reversible points and plates of 10 mm in thickness were cast. Ductile iron was first melted in an induction furnace with acid lining, modified with FeSiMg master alloy in ladle, inoculated with ferrosilicon on a filter, and gravity-cast into moulds of bentonite bonded sand. Used as patterns were the original ploughshares and reversible points, with the openings for fastening bolts having been pre-cast with the aid of cores. Ductile iron plates were then cut and milled to provide comparative plates, in which openings were bored.

Ploughshares, reversible points, and comparative plates were heat treated by austempering using two heat modes. Heating in a salt bath to a temperature of 880°C yielded an austenitic structure. After austenitization, the specimens and test castings were quickly transferred into another salt bath, with a temperature of 380°C (200°C in the second variant) and after a holding time of two hours they were left to cool in air. The mechanical properties for the two variants are given in Table 2.

After the heat treatment the comparative plates were cut into cubes for abrasive cloth tests. All the test specimens were additionally marked and weighed.

Table 2. Mechanical properties of ADI

Heat treatment	HRC	R_m (MPa)	$Rp_{0.2}$ bending strength (MPa)
880/380/2h	32	855	550
880/200/2h	51	1260	950

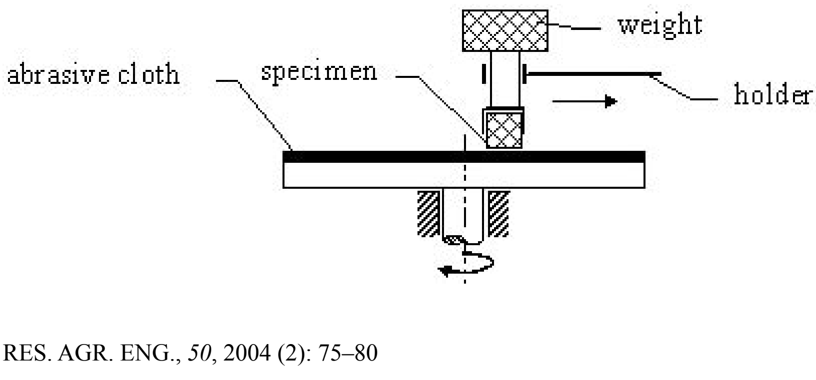


Fig. 3. Schematic diagram of device with abrasive

RESULTS AND DISCUSSION

Ploughshares and reversible points of variant 1 of ADI (880/380/2h) were mounted on one side of a four-furrow reversible plough while the original Kverneland ploughshares KV 16” No. 9 and reversible points were mounted on the other side. This provided for identical operating conditions for both types of working tools. Using this plough set, 24.7 ha of land (i.e. 3.1 ha per 1 plough body) were ploughed. The mass decrements in ploughshares and reversible points are given in Fig. 4.

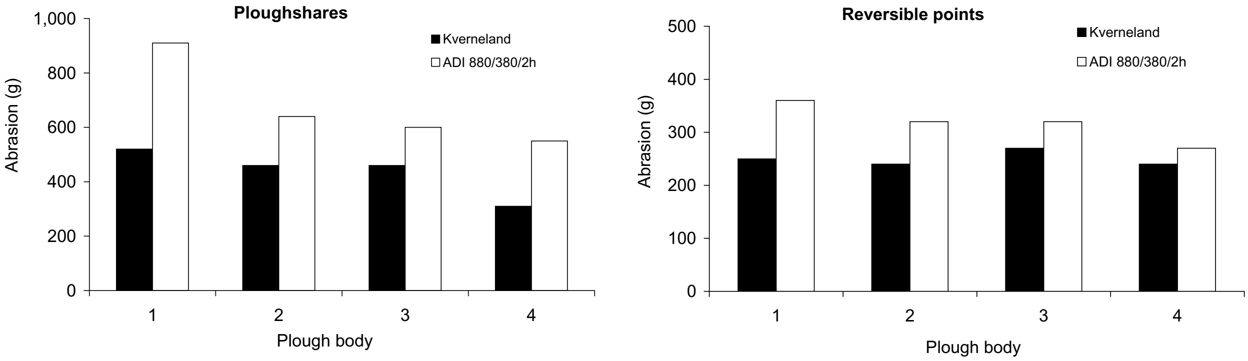


Fig. 4. Wear of working tools after ploughing 3.1 ha

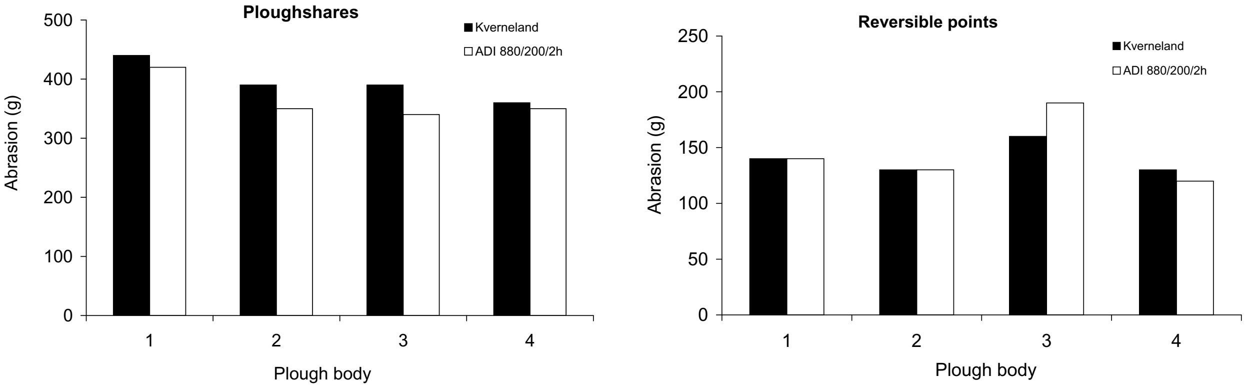


Fig. 5. Wear of working tools after ploughing 2.4 ha

The differences between average wear values for the original Kverneland working tools and the austempered ductile iron tools were established by means of the *t*-test ($\alpha = 0.05$). The wear difference between the Kverneland and the ADI (880/380/2h) ploughshares and reversible points is statistically inconclusive. With this heat treatment mode the abrasive wear for ADI tools is higher than for the original tools.

Working tools made of variant II of ADI (880/200/2h) were tested in the same way, being again compared with new original tools. The mass decrements in ploughshares and reversible points after ploughing 19.1 ha of land (i.e. 2.4 ha per 1 plough body) are given in Fig. 5. In this case the wear difference between the Kverneland and the ADI (880/200/2h) ploughshares and reversible points is statistically inconclusive. As regards resistance to abrasive wear, working tools made of ADI 880/200/2h are comparable with the original tools.

In the second stage of plough tests, comparative plates of 80 × 40 × 8 mm were tested. They were fixed by countersunk bolts to the transition between the ploughshare and the mouldboard of each plough body (Fig. 6). At definite intervals the specimens were repeatedly dismounted, cleaned of undesirable soil residues, and weighed. The parameter monitored was the mass decre-

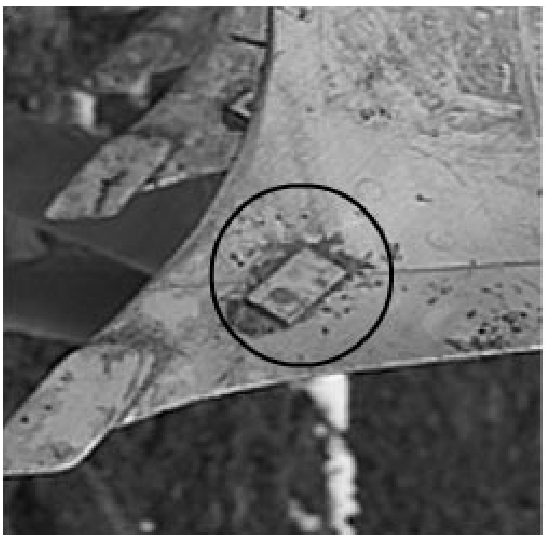


Fig 6. Fixation of tested samples

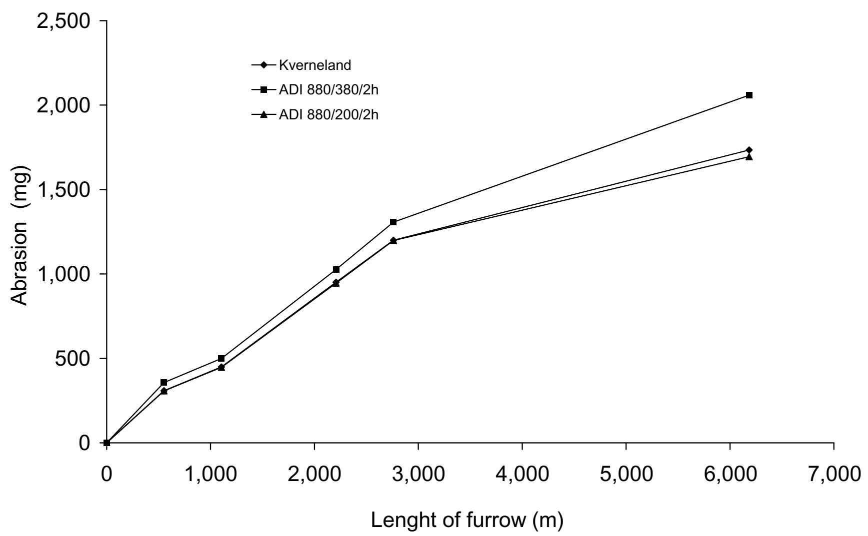


Fig. 7. Wear of comparative plates

ment in plates in dependence on the length of ploughed furrow (Fig. 7). The not quite smooth shape of the curves was due to the different soil conditions during the measurement.

Fig. 8 gives the relative wear of test specimens in ploughing and laboratory tests.

In all the three types of test specimen used in the ploughing test (ploughshares, reversible points, and comparative plates) the results correspond to material hardness. Working tools made of variant I of ADI (880/380/2h) exhibit greater wear than the original Kverneland tools do while the wear of tools made of variant II ADI (880/200/2h) is comparable with original tools. Measurement results indicate that using ductile iron castings for the manufacture of wear resistant machine parts is a possible development trend.

Results of the laboratory tests using emery cloth (ČSN 01 5084 Standard) do not tally with the ploughing tests (Fig. 8). Surprisingly, the wear of the specimens of both ADI variants is lower than in specimens taken from original Kverneland ploughshares. Increased wear resistance of ADI may be due to transformation hardening. In this case we cannot derive from the laboratory test results any conclusions that would be valid for ploughing conditions.

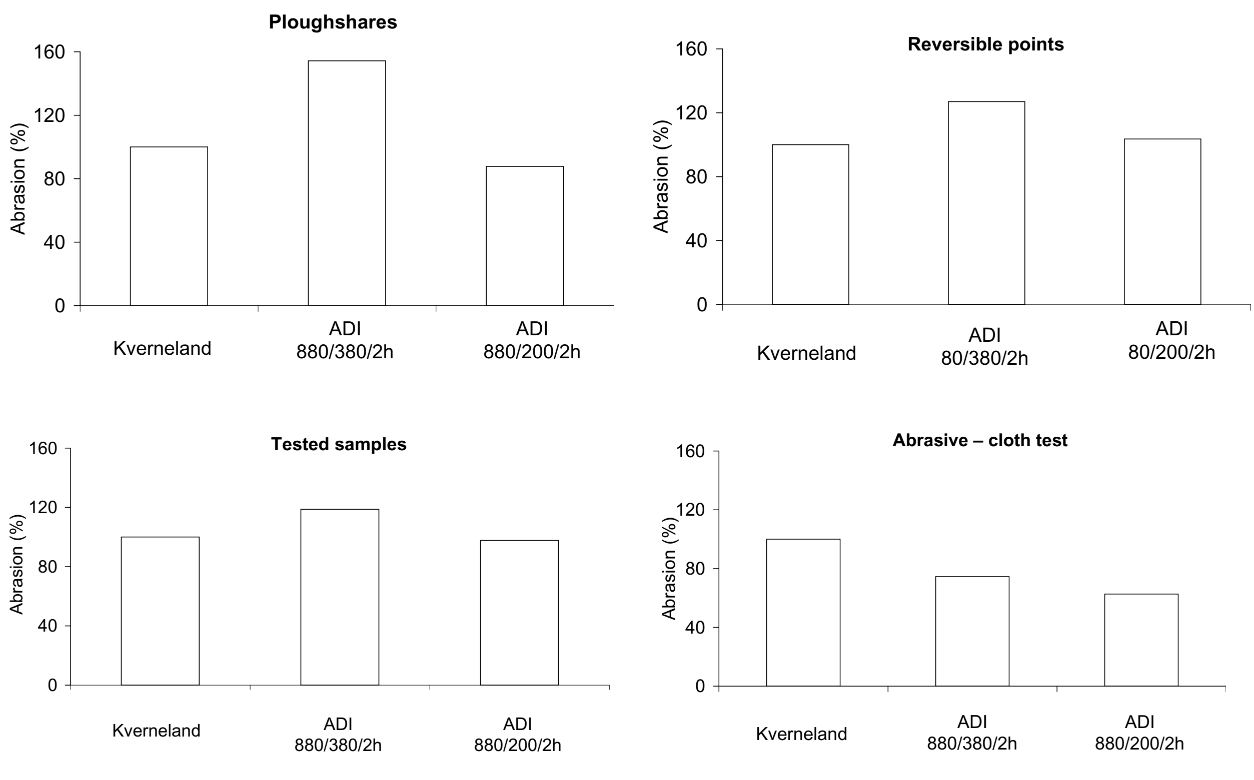


Fig. 8. Wear of test specimens compared with original Kverneland pieces

CONCLUSION

Kverneland ploughshares and reversible points are of top quality, they exhibit both outstanding resistance to abrasive wear and resistance to impact loading and strokes. Given a suitable heat treatment, the wear of working tools made of austempered ductile iron (ADI) is comparable with that of original Kverneland working tools. An appropriate combination of chemical composition and heat treatment can yield in ductile irons an optimum combination of strength, toughness and wear resistance for different ploughing conditions. Working tools can be made of ADI at 50% of the cost of original tools. In soil conditions corresponding to the experiment this represents in the case of ploughshares a saving of CZK 27 per ha. Casting ductile-iron working tools of complicated shapes can be economically advantageous even in small batches. However, in the case of soils containing large stones it cannot be excluded that ploughshares and reversible points made of ADI will break.

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Využití tvárné litiny pro výrobu plužních čepelí

ABSTRAKT: Životnost a spolehlivost strojů pro základní zpracování půdy ovlivňuje zejména abrazivní opotřebení. Pracovní nástroje těchto strojů se vyrábějí především z ocelí. Příspěvek se zabývá možností výroby plužních čepelí a dlát z izotermicky zušlechtěné tvárné litiny (ADI). Autoři zjišťují odolnost proti abrazi pracovních nástrojů z ADI a srovnávají s materiálem předního světového výrobce plužních čepelí. Při vhodném režimu tepelného zpracování ADI se dosáhne srovnatelné odolnosti proti abrazi s původními nástroji.

Klíčová slova: abrazivní opotřebení; plužní čepele; tvárná litina; izotermické zušlechťování

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