Whitepaper ACO Eurobar® ductile iron

Is ductile iron an alternative to lead-alloyed free-machining steels?

Lead-alloyed steels find wide use in the engineering industry thanks to their excellent machining characteristics. Despite attempts to develop alternatives, leaded free-machining steels are still invariably the materials of choice for components which are lightly loaded but which require extensive machining in their manufacture. Current legislation in the EU permits lead additions in free-machining steels up to a maximum of 0.35%.

Because of the risks in steelmaking, for both environment and personnel, the manufacture of leaded steels is in many countries forbidden. By way of contrast, it would seem to be widely accepted in the engineering industry that there are no risks involved in using lead-alloyed steels. However, recent studies indicate that airborne levels of lead can exceed those permitted in dry-machining at high speeds. Furthermore, in lubricated machining, contaminated cutting fluid means problems and costs for disposal.

The above scenario implies that from an environmental standpoint, there is reason to question the use of lead as a machinability enhancer for steel. Grey cast iron has even better machinability than lead-alloyed steels but its mechanical characteristics are inferior. Ductile iron, on the other hand, has equivalent or superior mechanical properties to most lead-containing steels. This note compares a lead-alloyed steel and a ductile iron in order to elucidate if the latter, in relation to machinability, constitutes a realistic replacement alternative.

Materials investigated

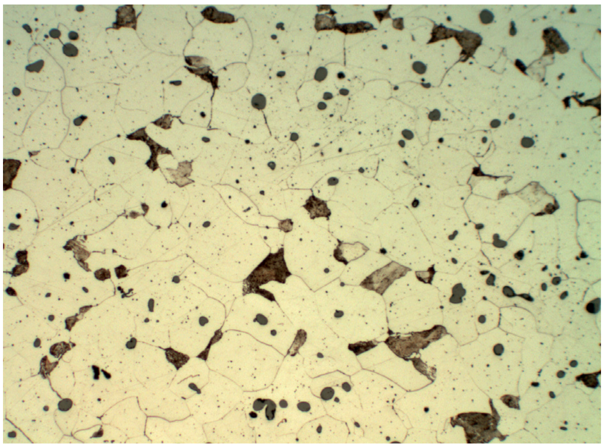
The materials tested in the form of machined 120 mm diameter round bar were:

- Annealed continuous-cast ductile iron EN-GJS-400-18C-LT as specified in EN 16482;
- Low-carbon free-machining steel, 11SMnPb30 as specified in EN 10277-3. The tested material contained 0.29% of sulphur and 0.27 % of lead.

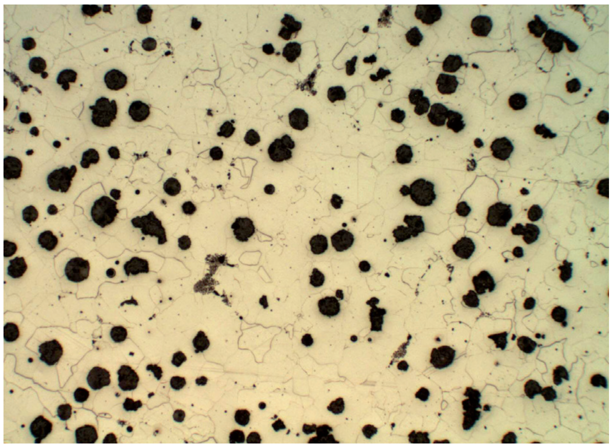
The mechanical properties of the two materials are tabulated below from which it will be evident that the ductile iron was somewhat harder.

	$R_{p0.2}$, N/mm²	R_m, N/mm²	A_5, %	Hardness, BHN
EN-GJS-400-18C-LT	301	427	17.3	144
11SMnPb30	245	387	27.4	119

The micrographs show the metallurgical microstructure in the two materials.



11SMnPb30



EN-GJS-400-18C-LT

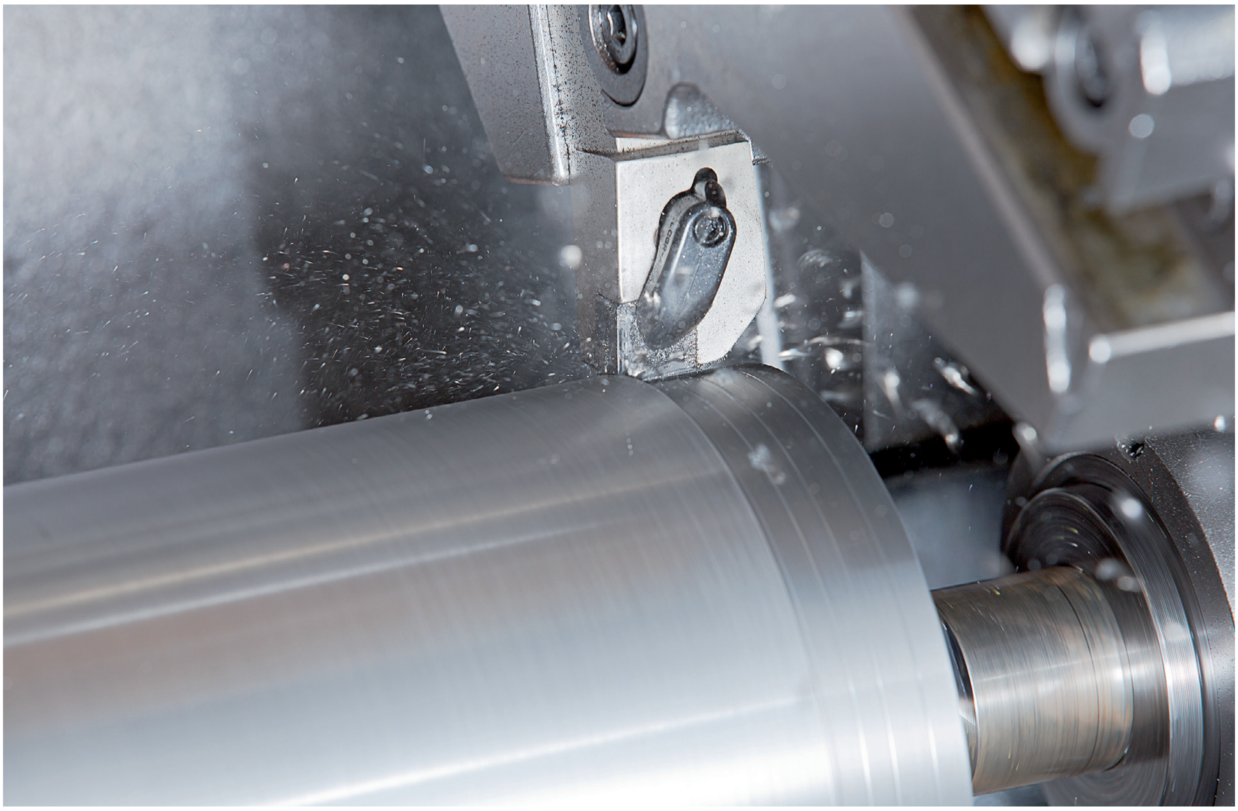
Machinability testing

The machinability of the free-machining steel and the ductile iron was compared in turning and drilling. The testing proceeded in two steps:

1. A standardised test for comparison purposes using uncoated tooling of older type.
2. An optimised test with modern coated tooling specifically adapted for machining in each material.

Turning

All turning tests were made on an Oerlikon Boeringer VDF 180 lathe. The standard test used an uncoated P30-carbide SPGN-insert; machining was dry with depth of cut 1 mm and feed 0.125 mm/rev (see photo). A Taylor diagram was established for each material whereby V_{30}, the cutting speed corresponding to a tool life of 30 minutes, could be determined. The tool-life criterion was 0.3 mm flank wear.



Standardised turning test in EN-GJS-400-18C-LT

In the tooling-adapted tests, the depth of cut was 2 mm, feed 0.25 mm/rev. with 8 % oil emulsion for cooling. Again, V_{30} corresponding to a flank wear of 0.3 mm was determined. The following insert selections were made:
Steel: SECO CNMG 120408-M6-TP2500 (ISO P10-P30 range with a multiple layer Ti(C,N)-Al_2O_3-TiN).
Ductile iron: Sandvik CNMG 120408-KM-3205 (ISO K01-K15 range with coating similar to the above but with a thicker Al_2O_3-layer).

Drilling

A Modig 7200 CNC-machining centre was used for the drilling tests (lubricated: 12% emulsion, 20 bar pressure). The materials were first compared in a standard test using a high-speed steel (HSS) drill and then in a complementary test with PVD-coated solid-carbide tools. Blanks with suitable thickness cut from the bars provided a flat surface.

A Wedevåg Double-X Ø 5 mm uncoated HSS-drill was used for the standard test in which the cutting speed giving an average drilled length of 1000 mm (V_{1000}) was established. The feed rate was 0.15 mm/rev., the hole depth 12.5 mm and complete tool failure was the wear criterion.

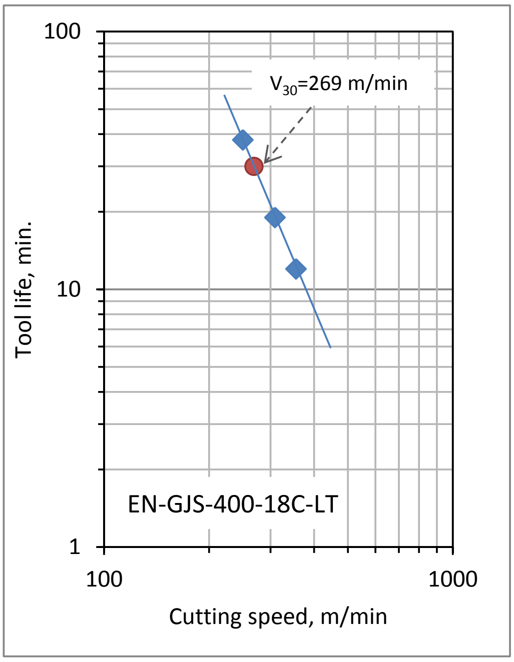
Tests with solid carbide drills were performed as detailed below.
1. Tool: DOF Tools P+ Ø 5 mm with internal cooling channels. Hole depth: 25 mm, no re-tracking. Cutting speed: 200 m/min (12 730 rpm). Feed: 0.4 mm/rev (5 090 mm/min) corresponding to 0.3 s/hole.
2. Tool: DOF Tools P+ Ø 13.4 mm with internal cooling channels. Hole depth: 40 mm, no re-tracking. Cutting speed: 300 m/min (7 075 rpm). Feed: 0.8 mm/rev (5 660 mm/min) corresponding to 0.4 s/hole.

Results from machinability testing
Turning tests

In the standardised test with an uncoated carbide insert, the following results were obtained for V_{30}.

Free-machining steel, 11SMnPb30:	311 m/min
Ductile iron, EN-GJS-400-18C-LT:	269 m/min

The lead-alloyed, free-machining steel performed about 15% better. The diagram shows a Taylor plot for the ductile iron.



In the tests with adapted CVD-coated tooling, the following V_{30}-values were measured:

Free-machining steel, 11SMnPb30:	500 m/min
Ductile iron, EN-GJS-400-18C-LT:	442 m/min

Again, the leaded steel is about 15% better.

Ductile iron

Drilling tests

The standardised test using an uncoated high-speed-steel drill Ø 5 mm gave the following results for V_{1000}.

Free-machining steel, 11SMnPb30:	225 m/min.
Ductile iron, EN-GJS-400-18C-LT:	150 m/min.

The better result for the steel was expected since it is well known that the presence of lead is particularly positive in high-speed-steel machining.

In the tests with coated solid carbide drills, the following data were measured.

Ø 5 mm, speed 200 m/min, hole depth 25 mm
Free-machining steel, 11SMnPb30:
2408 holes (drilled length 60.2 m)
Ductile iron, EN-GJS-400-18C-LT:
2408 holes (drilled length 60.2 m)

The test was stopped after this large number of holes; the flank wear was only 0.1 mm and the drills were still fully usable. Limitations on machine spindle speed precluded testing of this smaller diameter at higher cutting speeds.

A higher cutting speed was achieved with the larger-diameter drill.

Ø 13.4 mm, speed 300 m/min, hole depth 40 mm
Free-machining steel, 11SMnPb30:
1576 holes (drilled length 63 m)
Ductile iron, EN-GJS-400-18C-LT:
1499 holes (drilled length 60 m)

The flank wear at the end of this test was 0.25 mm for both materials; the drills were still usable but quite close to the end of their lives (estimated life 70-75 m).

Comments

The results reported in this note indicate that in turning, a low-carbon lead-alloyed steel 11SMnPb30 has somewhat superior machinability to the ferritic ductile iron EN-GJS-400-18C-LT. However, in drilling with carbide tooling, the two materials show equivalent machinability. In comparing the machining results for the two materials, it should be borne in mind that the ductile iron was somewhat harder than the steel.

For steels, there is evidence that machinability-enhancing additions like sulphur and lead have greatest effect in operations such as turning where there is continuous contact between tool and workpiece. When contact is more intermittent as in drilling or milling, their positive influence is less. This seems to be borne out by the present study.

For all practical purposes, the data generated here indicate that EN-GJS-400-18C-LT ductile iron could for engineering components replace free-machining steels containing lead without any serious negative consequences for productivity or tool life in machining operations. In other words, essentially the same speeds, feeds and cut depth can be used and it is only necessary to adapt the tool to a carbide grade and geometry tailored specifically to cast iron in general and ductile iron in particular.

A further advantage accruing from replacement of steel by ductile iron is the possibility to use tooling based upon silicon nitride and sialon ceramics. The high silicon content of the iron counteracts diffusional wear at high cutting-edge temperatures; this type of degeneration disqualifies such tooling materials for machining of steel.

Apart from environmental ramifications, there are other benefits to be gained from replacing lead-alloyed steels with continuous-cast ductile iron:

- Better mechanical properties,
- 10 % lighter,
- Greater damping capacity,
- Easy to achieve high surface hardness via straightforward heat treatment.

William Roberts on behalf of ACO Eurobar GmbH

For more information please contact:

ACO Eurobar GmbH

Bernd Gründemann
Am Gusswerk 8
67663 Kaiserslautern
Germany

Tel.: +49 631 2011-0
E-Mail: info@aco-eurobar.com