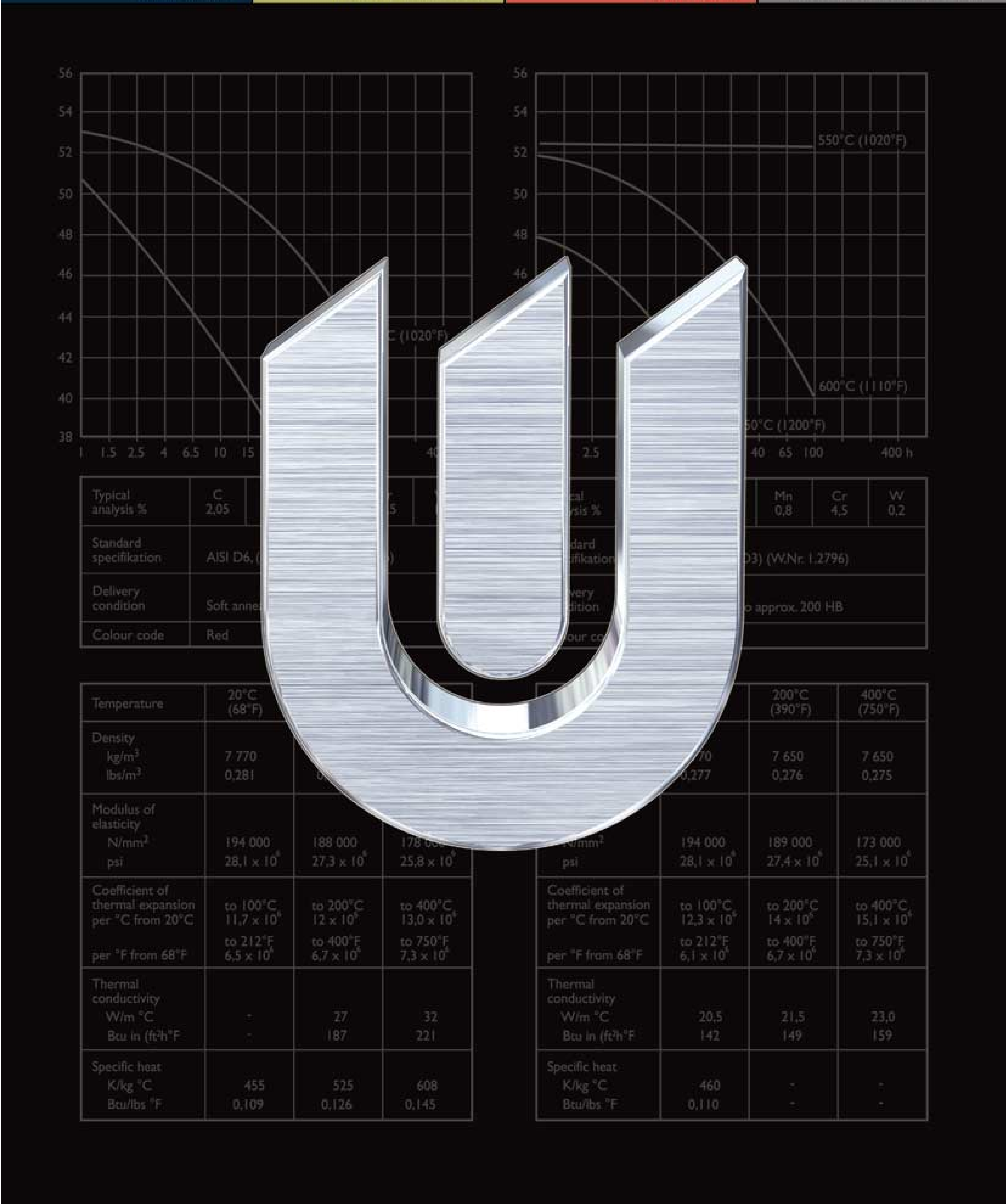
Polishing mould steel

COLD WORK | **PLASTIC** MOULDING | **HOT** WORK | **HIGH** PERFORMANCE STEEL



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Why strive for a high surface finish?

The increased use of plastic products has created a higher demand for mirror finish of moulding tools. The highest demands for surface finish are in the optical lens mould where an extreme requirement on polishability is desired.

However, in general there are other advantages with high surface finish, including:

- **Easier ejection of the plastic parts from the moulding tool** (applies to most plastics)
- **Reduced risk of local corrosion**
- **Reduced risk of fracture or cracking** due to temporary over loading or pure fatigue.

This brochure reviews the factors that affect the polishability of mould steels and gives recommendations on how to economically obtain the required finish on the main steel grades used. In making these recommendations, it is recognized that the skill, experience and technique of the polisher plays an extremely important role in achieving the desired surface finish.

Judging surface finish

Two things are important when judging the surface of the mould. The surface must first have a geometrically correct shape without any long macro waves. This macro shape is mostly an inheritance from earlier grinding and stoning steps.

Secondly, the mirror finish of the mould surface must be free from scratches, pores, orange peel, pitting (pin-holes) etc. The surface finish is normally judged by the naked eye. There are certain difficulties involved in such a visual evaluation. A "flat" surface can look perfect despite the fact that it is not geometrically completely flat. Thus, the eye can be "fooled".

In more sophisticated cases, the finish can be judged by instrumental methods, such as optical interference techniques.

Factors which affect polishability

The surface smoothness which can be achieved by polishing steel depends on factors such as:

- **Tool steel quality**
- **Heat treatment**
- **Polishing technique.**

In general, it can be stated that polishing technique is the most important factor. If a suitable polishing technique is used it is almost always possible to achieve acceptable results, providing a correctly heat treated, good quality tool steel is used. *If however, an unsuitable technique is used, even the best steels can be ruined.*

THE TOOL STEEL QUALITY

Particles or areas in the steel surface which deviate from the matrix in terms of hardness and other properties can cause problems during polishing. Slag inclusions of various types and porosities are examples of such undesirable constituents. To improve the polishing properties, Uddeholm uses vacuum degassing and electro-slag refining (ESR) techniques in the production of its mould steel grades.

Vacuum degassing reduces the risk of large slag inclusions and hydrogen embrittlement and also produces a more homogeneous material.

ESR treatment greatly improves properties from the viewpoint of polishability, even better than those achieved by vacuum degassing. ESR treatment reduces the amount of slag inclusions in the steel and ensures that the remaining slag inclusions which cannot be avoided will be small and evenly distributed throughout the matrix, as shown in figure 1.

STAVAX ESR and *OPTIMAX* stainless mould steels, produced by the ESR technique, have proved particularly suitable for moulds with the highest surface finish requirements, e.g. optical lenses.

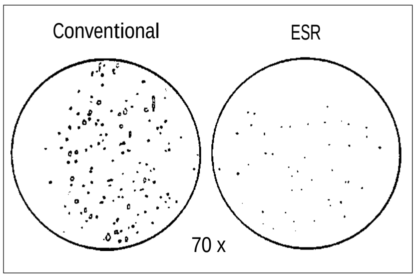


Figure 1. A typical inclusion picture in conventional and ESR-material. (An "inclusion picture" is made up from 70 superimposed photographs at high magnification.)

Lens mould with extreme demand on polishability. The material choice was STAVAX ESR.

HEAT TREATMENT

Heat treatment can affect polishability in many ways. A case-hardening steel which has been overcarburized is likely to have an unsuitable structure for polishing. This is caused by the creation of small oxide particles under the steel surface, leading to polishing problems. Decarburization or recarburization of the surface during heat treatment can produce variations in hardness, resulting in polishing difficulties.

POLISHING TECHNIQUE

Different steel grades effect on polishing techniques

Most Uddeholm mould steels, when used at the same hardness levels, take similar polishing times when using standard polishing techniques. Exceptions to this are *STAVAX ESR* and *OPTIMAX* stainless mould steels. These grades are capable of producing the very best surface quality, but many mouldmakers use a slightly different polishing technique to achieve it. The important thing is to grind to as fine a surface finish as possible before starting the polishing operation. Great importance is placed on stopping the polishing operation **immediately** the last scratch from the former grain size has been removed.

Different hardnesses effect on polishing technique

Higher hardness levels make the mould steel more difficult to grind but give higher surface smoothness after polishing. However, harder mould steels require a slightly longer polishing time to achieve higher surface finishes. With higher hardness levels, over-polishing is less likely to be a problem.

Grinding and stoning of moulds

PRACTICAL HINTS

Normally, a mould cavity is produced by means of milling, EDM'ing or hobbing. If a very smooth surface is desired, the following sequences should be followed:

After milling: rough grinding, fine grinding and polishing.

After EDM'ing: fine grinding and polishing.

After hobbing: a single polishing operation after heat treatment.

It should be emphasized that the grinding operation forms the basis for a rapid and successful polishing job. In grinding, the marks left by the rough-machining operation are removed and a metallically pure and geometrically correct surface is obtained. Certain rules should be followed to facilitate the work and ensure good results. This applies to both mechanical grinding and manual stoning.

- The grinding operation must not generate so much heat and pressure that the structure and hardness of the material are affected. Use plenty of coolant.
- Use only clean and free-cutting grinding tools with soft stones for hard surfaces.
- Between each change of grain size, the workpiece and hands should be cleaned to prevent coarse abrasive particles and dust being carried over to the next stage with a finer grain size.
- The finer the grain size used, the more important is the cleaning operation between each change of grain size.
- When changing to next next-finer grain size, grind in a direction at about 45° to the previous grinding direction until the surface only shows scratches from the present grinding step. After scratches from the previous step have disappeared continue for about 25% longer time before changing to the next grain size (except for *STAVAX ESR* and *OPTIMAX*). This is to remove the "deformed" surface layer caused by mechanical stresses induced during previous grinding operations.
- Changing grinding direction is also important to avoid the formation of irregularities and relief patterns.
- When grinding large, flat mould surfaces, avoid hand-operated grinding discs. The use of a stone reduces the risk of obtaining large shape irregularities.

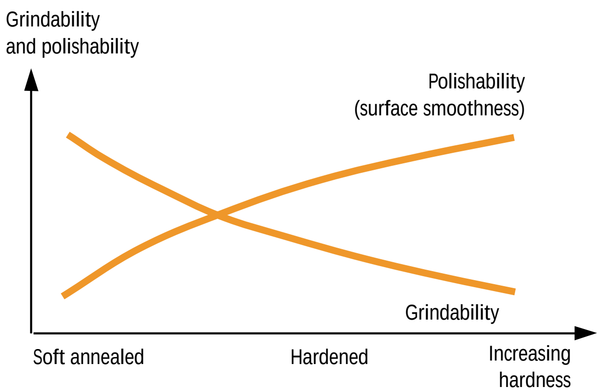


Figure 2. The relationship between increasing hardness levels, grindability and polishability

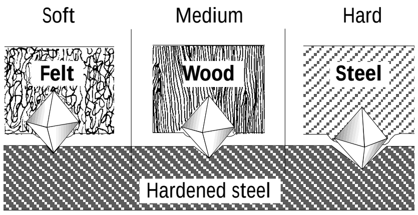
Polishing of moulds

PRACTICAL HINTS

Diamond paste is the most common abrasive agent used in polishing.

Optimum performance is obtained with the right paste, on the right polishing tool. The most common polishing tools are sticks, pads and blocks for manual use and bobs, brushes and discs for machines.

Polishing tools are available in materials of different hardnesses from metals through different types of fibre (e.g. wood, synthetic fibre) to soft felt. The hardness of the polishing tool affects the exposure of the diamond grains and the removal rate. The following figure illustrates this:



Time-consuming and expensive polishing can be cut by observing certain rules.

Above all, cleanliness in every step of the polishing operation is of such great importance that it cannot be overemphasized.

- Polishing should be carried out in dust- and draughtfree places. Hard dust particles can easily contaminate the abrasive and ruin an almost finished surface.
- Each polishing tool should be used for **only one** paste grade and kept i n dust-proof containers.
- The polishing tools gradually become "impregnated" and improve with use.
- Hands and workpiece should be cleaned carefully between each change of paste grade, the workpiece with a grease solvent and the hands with soap.
- Paste should be applied to the polishing tool in manual polishing, while in machine polishing, the paste should be applied to the workpiece.
- Polishing pressure should be adjusted to the hardness of the polishing tool and the grade of the paste. For the finest grain sizes, the pressure should only be the weight of the polishing tool.
- Heavy material removal requires hard polishing tools and coarse paste.
- Finish polishing of plastic moulds should be carried out in the release directional.
- Polishing should start in the corners, edges and fillets or other difficult parts of the mould.
- Be careful with sharp corners and edges, so they are not rounded off. Preferably use hard polishing tools.

Polishing a plastic mould.

Typical polishing sequences

The choice of grinding and polishing sequences is determined by the experience of the operator and the equipment he has at his disposal. The properties of the material can also affect the sequence.

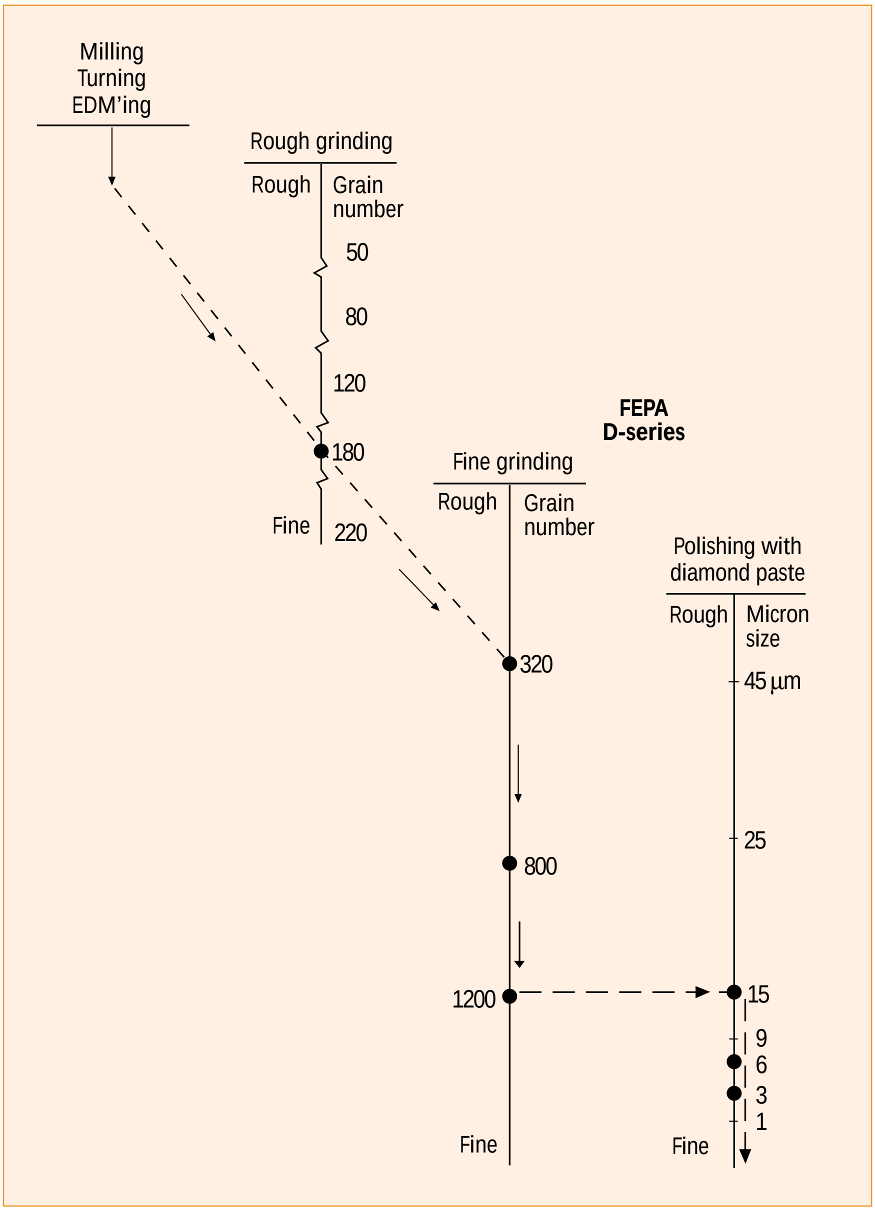
In polishing there are two methods used. In the first method, a paste with a certain grain size is selected and a hard polishing tool is used initially, after which softer and softer polishing tools are used. In the second method, a medium-hard polishing tool is selected and coarse paste is used initially. Then the grain size of the paste is gradually reduced towards finer and finer pastes. A combination of these two methods can be recommended.

Example of sequences:

– Start with a hard polishing tool and a coarse paste.
– Then change to a softer polishing tool with the same paste.
– Then use a medium-hard polishing tool and a medium-coarse paste.
– Change to a soft polishing tool with the same paste.
– Finally, use a soft polishing tool and a fine paste.

Examples of how to combine polishing tool and grain size of the abrasive.

Cloth Hardness	Cloth material	Abrasive Micron
Very hard	Steel Nylon reinforced	Diamond 45, 15, 6, 3
Hard	Coated nylon	Diamond 9, 6, 3
Hard	Silk	Diamond 15, 6, 3, 1 Alumina
Hard	Paper	Diamond 15, 6, 3 Alumina
Soft	Wool	Diamond 6, 3, 1
Soft	Dense nylon velvet	Diamond 3
Very soft	Velvet	Diamond 1 and smaller Alumina MgO OP-S

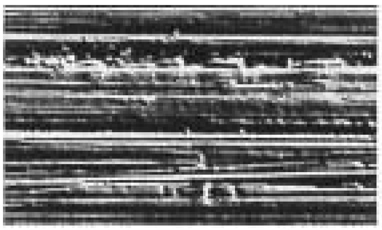


This diagram shows example of how the polishing sequence can be selected.

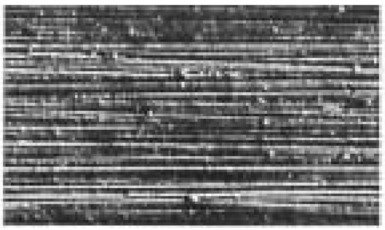
Grain size conversion table

Grain sizes µm	Commercial grain number	FEPA grain number: F-series No.	F-series µm	FEPA grain number	D-series No.	D-series µm
5100–4000	4					
4000–3500	5					
3500–2830	6					
2830–2380	8			8		
2380–2000	10			10		
2000–1680	12			12		
1680–1410	14			14		
1410–1190	16			16		
1190–1000	20			20		
1000– 840				(22)		
840– 710	24			24		
710– 590	30			30		
590– 500	36			36		
500– 420	40			(40)		
420– 350	46			46		
350– 297	50			50		
297– 250	60			60		
250– 210	70			70		
210– 177	80			80		
177– 149	90			90		
149– 125	100			100		
125– 105	120			120		
105– 88	150			150		
88– 74	180			180		
74– 62	200			200		
62– 53	220			220		
		230	56,0 ±3			
53– 45	240	240	49,3 ±2	240	240	58,5 ±2
45– 37	280	280	41,5 ±1,5		280	52,2 ±2
37– 31	320	320	34,4 ±1,5		320	46,2 ±1,5
		360	28,2 ±1,5		360	40,5 ±1,5
31– 27	400	400	23,0 ±1,0		400	35,0 ±1,5
27– 22	500	500	18,2 ±1,0		500	30,2 ±1,5
22– 18	600	600	14,3 ±1,0		600	25,75±1,0
18– 15	700					
15– 11	800	800	10,6 ±1,0		800	21,8 ±1,0
11– 8	1000	1000	7,8 ±0,8		1000	18,3 ±1,0
		1200	5,6 ±0,5		1200	15,2 ±1,0
8– 5	2000				2400	10
5– 0	3000				4000	5

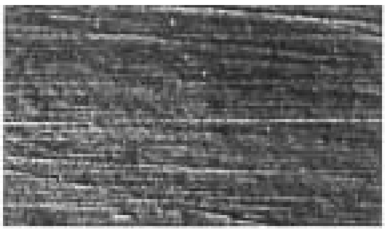
Surface roughness after grinding. Magnification x 300



Grain size 90–75 µm
Arithmetic Average micro inch 8

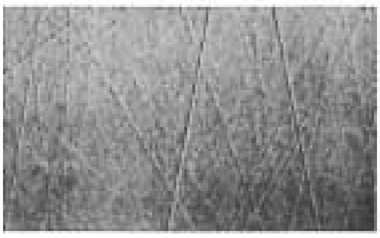


27–24 µm
2,8

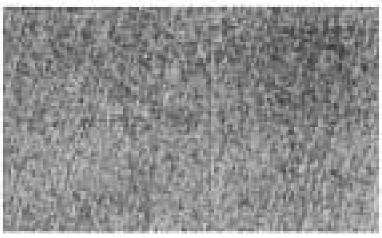


16–14 µm
1,2

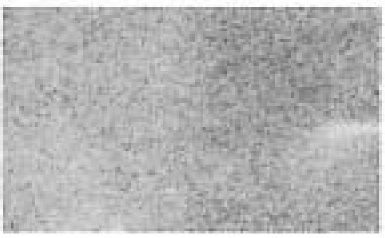
Surface roughness after using diamond paste on nylon cloth. Magnification x 300



Grain size 30 µm
Arithmetic Average micro inch 2,4



7 µm
0,4



1 µm
0,24

Different surface conditions prior to polishing

EDM'd surfaces are more difficult to grind than conventionally machined or heat treated surfaces. An EDM-operation should be finished with a fine sparking stage. If the fine sparking stage is performed correctly, there will be no problems. If not, a thin rehardened layer will remain on the surface. This layer is considerably harder than the matrix and must be removed.

A nitrided or case hardened surface is more difficult to grind than base material but takes a good surface finish after polishing. However, small defects produced in the surface layer do not always allow the extremely high surface finishes to be obtained.

A mould that has been flame-hardened or repair welded often shows a soft zone between the treated part and the base material. To avoid a ditch formation along the soft zone use a broad stone.

Surface roughness after different heat treatment methods

Many toolmakers ask the question: "How far should I go in grinding steps **before** heat treatment?"

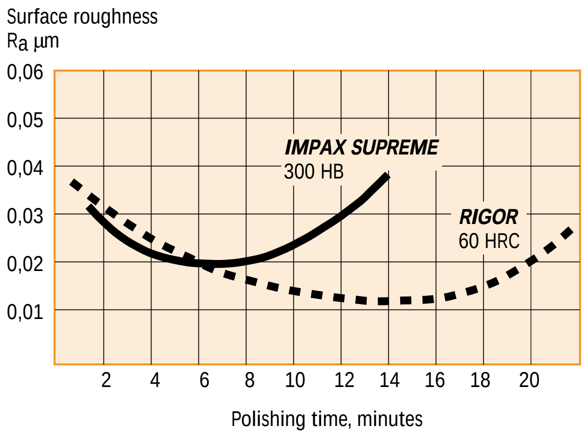
It should be borne in mind that during heat treatment some dimensional changes are likely to take place, possibly requiring a final finishing operation. Furthermore, the surface finish of the mould may be affected by the heat treatment medium. There is no point, therefore, in polishing a mould to a very high finish before heat treatment if size/shape changes and/or surface deterioration make further finishing operations necessary.

Polishing problems can be solved

The predominant problem in polishing is so-called "overpolishing". Overpolishing is the term used when a polished surface gets worse the longer you polish it. There are basically two phenomena which appear when a surface is overpolished: *"Orange peel"* and *"Pitting"* (pin holes). It should be pointed out that overpolishing often occurs in connection with machine polishing.

"ORANGE PEEL"

The appearance of an irregular, rough surface, which is normally referred to as "orange peel", may depend on a number of different causes. The most common is overheating or overcarburization from heat treatment in combination with high pressure and prolonged polishing. A harder material can better withstand a high polishing pressure, softer steels overpolish more easily. Studies have shown that the overpolishing effect occurs at different polishing times for different hardnesses.



The normal reaction of a person who sees that a surface has deteriorated is to increase the polishing pressure and continue polishing. Such a course of action will inevitably result in further surface deterioration.

Either of the following alternatives can be adopted to restore the surface.

Alt 1 Remove the defective surface layer by grinding the surface using the next-to-last grinding step prior to polishing. Start again at the final grinding stage. Use a lower pressure during polishing than before.

Alt 2 Stress-relieve at a temperature about 25°C (45°F) below the last tempering temperature. Regrind using the final grinding step prior to polishing until a satisfactory surface has been obtained. Start polishing again, but at a lower polishing pressure than before.

If the result is still not good, the hardness must be raised. This can be done in a number of different ways:

- Increase the surface hardness of the steel by means of nitriding or nitrocarburizing treatment.
- Heat treat the tool to a higher hardness.

"PITTING"

The very small pits which can occur in a polished surface generally result from slag (non-metallic) inclusions in the form of hard, brittle oxides which have been torn out from the surface by the polishing process. The causal factors which are of im-portance in this connection are:

- **Polishing time and pressure.**
- **Purity of the steel,** especially with regard to hard slag inclusions.
- **The polishing tool.**
- **The abrasive.**

One of the reasons why pitting can occur is the difference in hardness between the matrix and the slag inclusion. During polishing, the matrix will be removed at a more rapid rate than the hard slag particles. Polishing will gradually "undermine" the slag particle until the particle is torn out of the material by further polishing. This leaves a pit. The problem is most often encountered in the case of paste grain size less than 10 µm and soft polishing tools (e.g. felt).

One way to minimise the risk of pitting is to select high-purity mould steels that have ben subjected to vacuum-degassing or Electro-slag refining (ESR) during manufacture.

If pitting still occurs the following measures should be taken:

- Regrind the surface carefully using the next-to-last grinding step prior to polishing. Use a soft free-cutting stone. Then start with the final grinding step and then polish.
- When using grain sizes 10 µm and smaller, the softest polishing tools should be avoided.
- Polish for the shortest possible time and under lowest possible pressure.