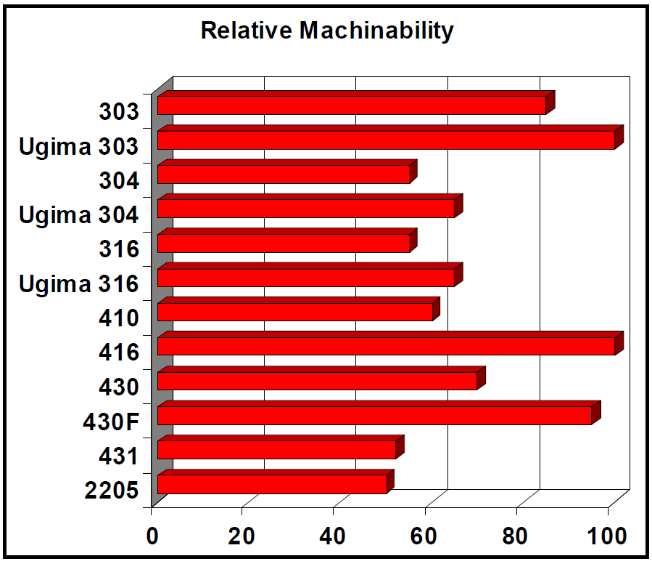
Atlas Tech Note No. 4
Machining of Stainless Steels

The stainless steels are in general more difficult to machine than carbon or low alloy steels, although there are very wide differences between different grades and conditions. The common austenitic (300-series) stainless steels in particular are often regarded as having poor machinability; this is due to their relatively high strength (particularly hot strength), low thermal conductivity, high thermal expansion and high work hardening rate. These often-useful properties can be a negative factor in respect of their ability to be fabricated – by other techniques as well as machining. Those organisations that understand these properties usually have very few problems in machining modern stainless steels.

Machinability of Stainless Steels

When considering non-free machining steels, the ferritic grades such as 430 are in general the easiest to machine as they are relatively low strength and also work harden at a low rate. The martensitic grades (410 and 431 for example) are also fairly readily machined if in the annealed condition, and can also be machined if hardened so long as they are tempered back to around 30HR C; this is a commonly supplied condition. The austenitic grades give most problems due to their "gummy" behaviour. Duplex grades do not have such high work hardening rates as the austenitics, but have substantially higher strengths, and so also have relatively poor machine abilities. The graph shows approximate machine abilities of grades, relative to Grade 416 free-machining stainless steel.



In general terms the three most important contributors to machinability of stainless steels are:

Sulphur content – a steel with less than about 0.015%S will be more difficult to machine; almost all plate, sheet and pipe has this very low sulphur content. Round and hexagonal bar steels in common grades 304 and 316 are usually made with between 0.02 and 0.03% sulphur. Free machining stainless steels (e.g. grade 303) have about ten times this amount.

Hardness – harder steels will be more difficult to machine. Smaller diameter round bars (up to about 26mm) that are drawn to final size are likely to be slightly less readily machined compared to larger, bars that are produced by annealing then turning to final size.

Improved Machinability – the "Ugima factor" gives a significant increase in machinability compared to the same grade in non-Ugima form.

Free-Machining Stainless Steels

"Free Machining" variants of austenitic, ferritic and martensitic grades exist – Grade 303 is a free machining version of Grade 304 and Grades 430F and 416 are free machining variants of 430 and 410 respectively. In each case the free machining version is created by the addition of Sulphur (about 0.2 to 0.3%) which is present in the steel as "stringers" of manganese sulphide running along the length of the material. These sulphides act as chip breakers and also reduce build-up of metal on tool edges, and enable significantly higher cutting speeds. Unfortunately, these sulphides also have some negative effects – they substantially reduce the corrosion resistance of the steel, in particular pitting resistance. The free machining grades also have reduced ductility and hence have limited capacity for cold heading and bending. They also have very poor weldability – structural welding is not recommended.

"Ugima" Improved Machinability Stainless Steels

A new generation of "Improved Machinability" stainless steels is available, under proprietary designations such as "Ugima". This exciting breakthrough has seen austenitic stainless steels with workability (weldability, formability) and corrosion resistances identical to their standard grade equivalents but with machinabilities substantially higher. In most instances the improvement in achievable cutting speed is about 20%. Other advantages are a substantial increase in tool life and improvement in workpiece surface finish. For many machine shops the improvement in tool life is the most valuable benefit. Ugima is stocked by Atlas in grades 304 and 316 and also in a super-machinable Ugima 303.

Cutting Fluids

These are necessary to:

- provide lubrication, reducing tool wear.
- cool the work piece and tool – very important for stainless steels.
- minimise edge build-up on the tool.
- flush away chips.

Both mineral oils and water-soluble oils are used in machining stainless steels; the mineral oils are more usual for heavy loads at low speeds when using high speed steel tooling, whereas water soluble oils tend to be used for higher speed machining with carbide tooling. Recommendations for exact cutting fluid selection should be sought from specialist suppliers of these products. No matter what cutting fluid is used it should subsequently be removed from the finished component. Lubricant left on can stain the component surface, can prevent wetting by later passivation treatment and may lead to carburisation in later welding or heat treatment operations.

Rules to Optimise machining of Stainless Steels

1. Both tool and work-piece must be held firmly. A very rigid machine tool is preferred.
2. A positive cut must be made at all times to ensure that work hardened material is removed.
3. Coolant / lubrication will almost always be necessary; this must be effectively applied.
4. A more powerful machine tool should be used; perhaps 50% above that required for carbon steels.
5. Tools such as drills, and reamers should be kept as short and as rigid as possible to reduce tendency for chatter. Heavy tools will also help conduct heat away.

Maintaining Corrosion Resistance of Machined Components

Some simple rules to maintain corrosion resistance of machined products:

- Cutting lubricants should be removed, especially if subsequent welding or heat treatment are to be carried out.
- Passivation treatment, usually by nitric acid solution, is strongly recommended to remove all traces of metal contamination and surface sulphide inclusions. Passivation is recommended

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after any surface cutting process if the item is to see service in an aggressively corrosive environment. Pickling is recommended to remove weld or heat treatment scale.

- Components should be machined with internal corners radiused and with all surfaces as smooth as possible so that crevice corrosion sites are minimised. This also improves resistance to fatigue fracture initiation.

Guide to Machining Speeds and Feeds

The following tables give some general guidance on machining of stainless steel bars. Much more detailed information is available from Atlas, particularly on the Ugima range of grades.

Grade	Drilling Speed (m/min) and Feed (mm/rev) for Drilling Hole Sizes as Below							
	3mm□		6mm□		12mm□		15mm□	
	Speed	Feed	Speed	Feed	Speed	Feed	Speed	Feed
303	22	0.07	24	0.10	26	0.20	29	0.20
Ugima 303	25	0.07	27	0.10	29	0.20	31	0.20
304, 316	11	0.07	13	0.10	13	0.20	15	0.20
Ugima 304, 316	12	0.07	14	0.10	14	0.20	17	0.20
416	18	0.07	26	0.10	26	0.20	28	0.20
410	11	0.07	14	0.10	14	0.20	16	0.20
431	7	0.07	8	0.10	9	0.15	10	0.15
430	15	0.07	17	0.10	17	0.20	19	0.20
430F	22	0.07	25	0.10	25	0.20	27	0.20

Notes:

1. High speed steel grade M1 drills of indicated diameter.
2. Lubricant assumed for all operations.
3. All work material in annealed (solution treated) condition. Lower cutting speeds apply for Cold Drawn or Hardened and Tempered condition.

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Grade	Turning: Speed (m/min) and Feed (mm/rev) for Turning with Tool Materials Listed							
	High Speed Steel		Carbide-Brazed		Carbide-Indexed		Carbide-Coated	
	Speed	Feed	Speed	Feed	Speed	Feed	Speed	Feed
303	21	0.4	122	0.4	197	0.4	247	0.4
Ugima 303	21	0.4	147	0.4	247	0.4	297	0.4
304, 316	15	0.4	87	0.4	117	0.4	147	0.4
Ugima 304, 316	16	0.4	108	0.4	157	0.4	202	0.4
416	39	0.4	137	0.4	177	0.4	197	0.4
410	24	0.4	107	0.4	157	0.4	177	0.4
431	13	0.2	75	0.2	111	0.2	126	0.2
430	27	0.4	112	0.4	127	0.4	187	0.4
430F	40	0.4	172	0.4	192	0.4	242	0.4

Notes:

1. This data is for roughing turning at 25mm diameter, with 3mm depth of cut.
   For finishing typical parameters would be: - Depth of Cut = 0.5 - 1.0mm, with
   Feed approximately 0.2mm/rev and Speeds increased by about 20% on above data.
2. Cutting tool materials P10 Carbide of each construction or M1/M2 High Speed Steel.
3. Lubricant assumed for all operations.
4. All work material in annealed (solution treated) condition. Lower cutting speeds apply for Cold Drawn or Hardened and Tempered condition.

References and Further Information

Datasheets for all the usual grades of stainless steels are available on the Atlas website; these give more general data on each grade.

Specific machining questions can be referred to engineers at Ugitech.