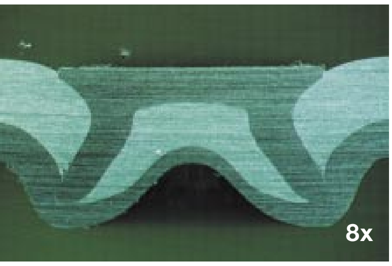
Metallographic preparation of fasteners

Struers

Application Notes

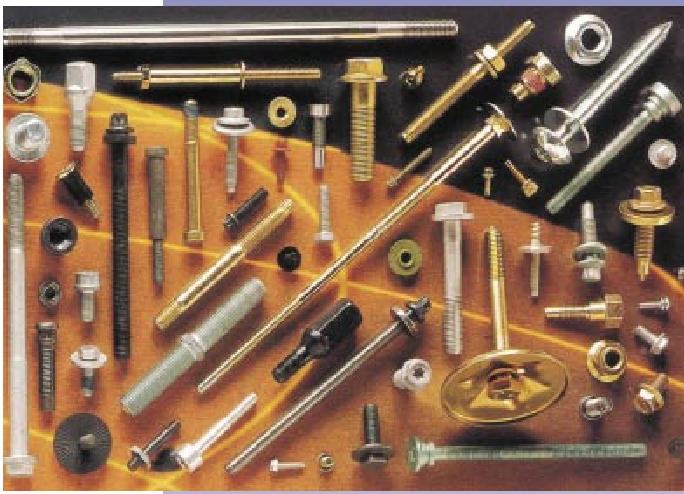
Pins and rods as means of mechanically connecting parts are one of the oldest construction elements. Rivets and screws were first made from precious metals and later from non ferrous metals and steels through forging and mechanical cutting. Not until the development of metals that were ductile enough to withstand the pressure of pressing and rolling tools, was cold forming adopted as a process used for the mass production of fasteners.



Riveted joint, steel rivet in aluminum

The main categories of mechanical joining are threaded fasteners such as bolts, nuts and screws, and non-threaded fasteners, like rivets and pins. Depending on the requirements regarding strength, torsion, environmental conditions etc. threaded and non-threaded fasteners are used for different applications. Both, rivets and screws have their specific fields of applications, such as aircraft and automotive industry, that are determined by specifications, safety and economical considerations.

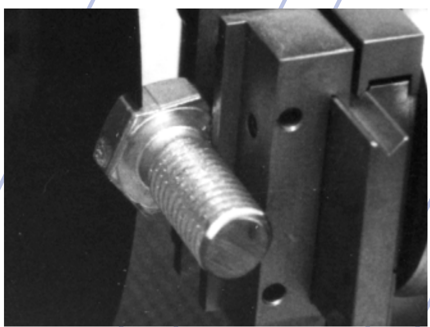
In many engineering applications, fasteners play a crucial role with regard to structural safety, and therefore have to be manufactured in compliance with specific standards. As a consequence, process and quality control procedures in general and metallographic examination in particular, are important in the production process. The tests range from checking dimensions, mechanical properties, and physical variables, to structure examination and quantitative analysis. Metallographic examination is part of the quality control regimen for producing fasteners, may it be spot checks of raw material, control and verification of forming and heat treatment processes or failure analysis.



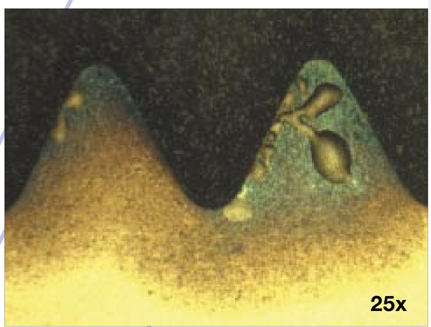
Difficulties during metallographic preparation:

Cutting: the size and shape of fasteners does not always allow for secure clamping and proper cross sectional cutting.

Mounting: shrinkage gaps on the thread and head of a fastener can make it difficult to achieve good edge retention and clean the sample properly in order to observe it microscopically.



Cutting excess of screw head off prior to mounting



Thread, staining due to shrinkage gap

Solution:

Cutting: Special holder for fasteners, precision cutting for small screws, or mounting of complete fastener with subsequent coarse grinding to the center.

Mounting: Proper degreasing and cleaning, use of mounting media material with the least shrinkage for hot compression or cold mounting.

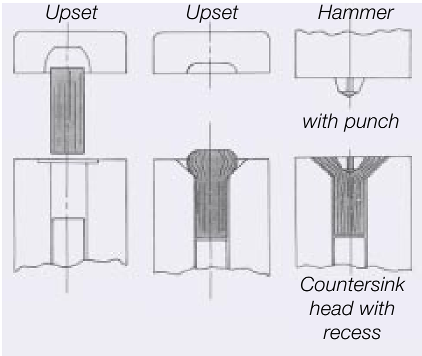
Production and application of fasteners

In the historical development of fastener production mechanical machining was important, especially for cutting threads. Today, chipless shaping (rolling) is a universal and economical production method, and machining is only used after the initial shaping, for finishing very special, high quality construction screws which require specific shapes, tolerances and surfaces.

Forming is carried out through either cold or hot pressing. Cold forming technology and metallurgy have advanced to a state where cold pressing has almost replaced hot forming in the production of fasteners.
For very large or complex shaped bolts, hot forming is still an option. Large section sizes, necessitate high cold forming forces resulting in an increased severity of the effects of cold work .
For cold forming a continuous wire is fed into an extrusion press, where through compression and reduction of the wire diameter in a die the fastener is shaped (Fig. 1). The threads are formed through a cold rolling operation (Fig. 2). As the threads are the most crucial part on a screw, correct rolling operation and subsequent heat treatment are very important. The cold working processes increase the hardness, and for quality steel fasteners, various heat treatment steps are carried out to achieve certain material properties for specific applications. Low carbon steels are carburized so that the centre is soft and ductile and the surface hard. Carbon steels are hardened and tempered, and depending on the application, temperature variations for austenitization and tempering are used to achieve different mechanical properties from the same raw material. Additional surface hardening, for instance on the heads, can be achieved through induction hardening. During the various stages of shaping and heat treating other steps such as pickling, cleaning and oiling take place.

Coating for corrosion protection is a last and usually a separate step from the actual manufacturing. For improved corrosion protection, fasteners are coated with manganese, zinc or iron phosphate and then oiled. Galvanizing with zinc and cadmium or chromium plating offer a higher corrosion protection, and so do vapor deposition coatings of cadmium and aluminium. (In some countries cadmium coatings are no longer applied for environmental reasons.)

Fig.1, Cold Heading.
A basic operation, it forms round wire stock into the essential various shapes while still "cold". A continuous, automatic operation it nonetheless must retain continuity of grain to assure the full integrity of the fastener.



In addition to low carbon and carbon steel fasteners for general applications, fasteners are made of high strength steel for construction and mechanical engineering applications, stainless steel for corrosion resistance, nickel and cobalt based alloys for high temperature applications, and titanium in the aircraft, medical and food industry. Non ferrous fasteners of brass and copper are used in connection with decorative metal rails and trimmings. Steel rivets are used in the automotive industry and titanium rivets are mainly used in aircraft outer body construction .

A main prerequisite for manufacturing good fasteners is quality raw material. There can be defects in the bars such as seams, voids in the centre of the bar, or incorrect heat treatment that produces the wrong grain size or structure. These can all lead to defects during the production of the fasteners. Metallographic quality control of raw material is therefore as important as the general production control.

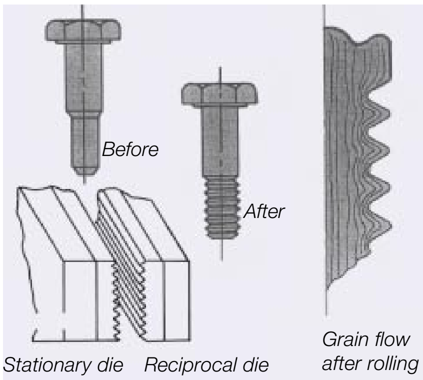
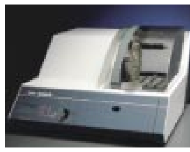


Fig. 2: Thread rolling.
A blank is rolled between two flat dies with precise parallel grooves of the thread type required. A cold - or warm - forming operation, rolled threads are strong and smooth - and no material is wasted.

Difficulties in the preparation of fasteners

The challenge of metallographic preparation of fasteners is their geometry. Usually the cut has to go through the centre of the screw and as the head is a protruding part, it can be difficult to clamp a rivet or screw securely to make a cross sectional cut. Large bolts can usually be cut in half without difficulties, however the thinner the screw is, the more difficult it is to cut.



The problem with geometry also influences the mounting, as the curves of thread and head are spots where shrinkage of mounting resin can occur preferentially. This is particular crucial on coated material, because coatings can not be examined properly without good edge retention.

Recommendations for the preparation of fasteners

To overcome the problems of **cutting and mounting** the following can be recommended:
For medium sized or thin screws a special holder with threads can be made that holds the part securely during cross sectioning (Fig. 3). For smaller screws or rivets the head can be cut off on one side, so that the screw can be laid flat into the mounting press. After mounting, the rest of the screw can be ground to the centre. An alternative is a special lower ram for the mounting press that has a recess on both sides into which the screwheads fit (Fig. 4).
For very small screws cutting is not efficient. They should be mounted with a piece of metal or plastic as a shim to level the screw

Fig. 3: Special holder for cutting screws

Fig. 4

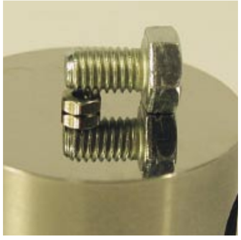


Fig. 5

Fig. 4:
Special lower ram for hot compression mounting

Fig. 5:
Shimming of screw for mounting

and then be ground to the middle after mounting (Fig. 5). The most efficient way of grinding fasteners is with a grinding stone on an automatic grinding machine, especially if large volumes have to be handled.
For hot compression mounting diallylphtalate with glass fibers (IsoFast), or phenolic resin with carbon fibers (PolyFast) are recommended, and for cold mounting epoxy resins (Epofix) as they have the least shrinkage. Before mounting, the parts should be thoroughly cleaned, with a degreasing agent such as acetone or ethanol. Particular attention should be paid to the threads and the radius below the head to make sure that the resin will adhere properly to the sample material.

Grinding and polishing
Once the fasteners are properly cut and mounted, the grinding and polishing has to be carried out according to the specific material. The wide range of fastener materials can not all be covered in this Application Note. We have selected two types of metal fasteners of which the preparation methods are given in tables 1 and 2. (For more detailed information on preparations, please refer to the Struers e-Metalog or Struers Application Notes). The examples for preparation data given in this Application Note are for brass shrews (Table 1) and screws

of low alloyed steel (Table 2). The data are for 6 mounted samples, 30 mm dia., clamped into a holder. The coarse grinding to the middle of the screws was carried out on the Struers automatic grinding machine Abraplan, the subsequent automatic fine grinding and polishing on Struers TegraPol.

Etching and structure interpretation
For etching of metallographic sections of fasteners the common, recommended etching solutions for the respective materials, such as carbon steel, titanium, brass, stainless steel etc. are used.
As mentioned above, during the production of fasteners mechanical defects

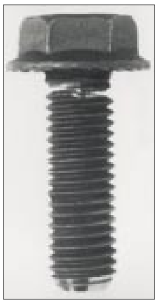


Fig. 6:
Fatigue fracture

such as burrs, cracks (Fig. 7a), folds and overlaps can occur, some of which can be detected through visual inspection or with non-destructive methods such as dye penetrant and magnetic particle inspection. The depth of these defects can be detected by metallographic means (Fig. 7b). Microstructural defects are mostly due to heat treatment such as overheating (Fig. 8), grain growth, intergranular oxidation and decarburisation (Fig. 9).
In many applications, the fracture of threaded fasteners can have serious consequences, consequently metallographic structural analysis is essential to find out what caused the fracture. They can occur through certain influences over time, such as mechanical, like bending and straining, or thermal and environmental exposure to lubricants, steam, chemical reagents etc. This can lead to fractures due to fatigue (Fig.6), torsion, embrittlement, corrosion and other multiple causes.

Summary
The term "fasteners" includes a wide range of threaded and non threaded bolts, screws, rivets and pins which all require specific raw material and produc-

Preparation Method
Brass screw

Grinding

	Step	PG	FG
	Surface	SiC-paper, #320	MD-Largo
	Suspension		DiaPro Allegro/Largo
	Lubricant	Water	
	rpm	300	150
	Force [N]	180*	180*
	Time	As needed	3 min.

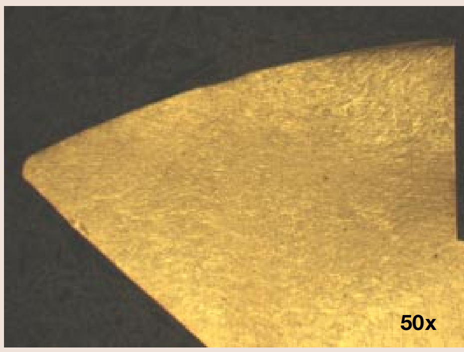
Polishing

	Step	DP	OP
	Surface	MD-Mol	MD-Chem
	Suspension	DiaPro Mol	OP-S**
	rpm	150	150
	Force [N]	180*	90*
	Time	3 min.	3 min.

Table 1

Fig. 7a: Split in head of carbon steel bolt caused by a seam.

Fig. 7b: Traverse section of the seam in the fig. 7a.
Echant: 3% Nital



Head of brass screw with flow lines from cold forming.
Etchant: Iron (III) chloride

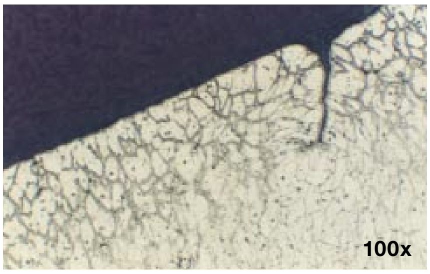


Fig. 8:
Melted grain boundaries due to overheating in heading. Nickel base alloy
Etchant: modified Kalling's

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Preparation Method
Bolt, alloyed steel

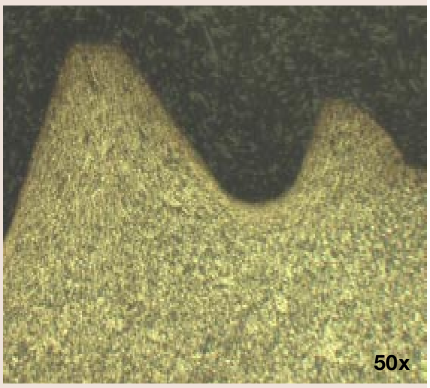
Grinding

Step	PG	FG
Surface	Stone 150#	MD-Allegro
Suspension		DiaPro Allegro/Largo
Lubricant	Water	
rpm	1500	150
Force [N]	200*	200*
Time	As needed	4 min.

Polishing

Step	DP 1	DP 2
Surface	MD-Dac	MD-Nap
Suspension	DiaPro Dac	DiaPro Nap B
rpm	150	150
Force [N]	200*	150*
Time	4 min.	1-5 min.

Table 2   * *Value for 6 mounted samples, 30 mm in diam. clamped in a holder.*



Thread of bolt, alloyed steel tempered
Etchant: 3% Nital

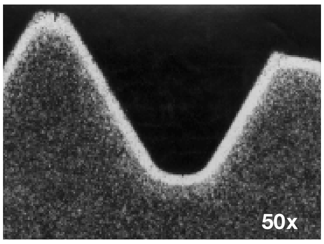
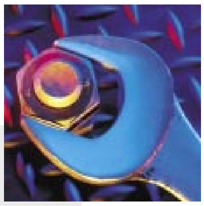


Fig. 9:
Section of thread showing decarburization
Etchant: 5% Nital

tion processes. Good metallographic quality control for raw material and production is essential to ensure quality fasteners. The metallographic checks are mainly for mechanical and thermal damages due to production and subsequent heat treatment. Interpretation of structure and defects requires some experience as the range of materials and shapes of fasteners is very wide.
Specific problems during the metallographic preparation are cutting and mounting, which can be overcome by using various helpful tools. The grinding and polishing procedure depends on the fastener material to be prepared and can be carried out on automatic equipment with a three or four step method.



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