There are literally hundreds of standards and specifications. For all types of applications, from bridges to spaceships. None are, however, as critical as those required for real-world motorsports applications. In an environment where lighter is faster there is clearly no room for redundancy systems, like those found in military and aerospace applications. The mere nature of Motorsports requires designers to produce fasteners that are light; yet produce toughness, fatigue and reliability factors that extend far beyond other acknowledged application standards. The design and production of fasteners, exclusively for racing, clearly involves many complex factors. Some so special no standards or design criteria exist; and so everyone at ARP is totally dedicated to the development and analysis of appropriate bolt designs exclusively for special applications. Designs that take into account the special loads and endurance that must be carried, the material selection, processing, and the methods of installation that will continue to deliver ARP quality and reliability.

The focus of the following material, prepared by the ARP engineering staff, could be called:

"MOTORSPORTS FASTENER ENGINEERING for the NON-ENGINEER."

It is hoped that by providing an overview of the engineering, design and production forces ARP applies daily, you – as the end user – will be better equipped to evaluate your initial fastener requirements, effectiveness and performance.

DESIGN PROCEDURES for AUTOMOTIVE BOLTS

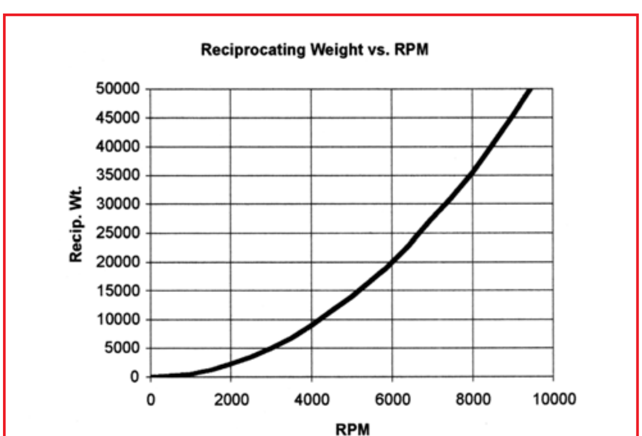
Presented by Dr. Kenneth Foster, PhD

The design of automotive bolts is a complex process, involving a multitude of factors. These include the determination of operating loads and the establishment of geometric configuration. The process for connecting rod bolts is described in the following paragraphs as an example.

The first step in the process of designing a connecting rod bolt is to determine the load that it must carry. This is accomplished by calculating the dynamic force caused by the oscillating piston and connecting rod. This force is determined from the classical concept that force equals mass times acceleration. The mass includes the mass of the piston plus a portion of the mass of the rod. This mass undergoes oscillating motion as the crankshaft rotates. The resulting acceleration, which is at its maximum value when the piston is at top dead center and bottom dead center, is proportional to the stroke and the square of the engine speed. The oscillating force is sometimes called the reciprocating weight. Its numerical value is proportional to:

$$(\text{Piston Weight} + \frac{\text{Rod Weight}}{3}) \times \text{Stroke} \times (\text{RPM})^2$$

It is seen that the design load, the reciprocating weight, depends on the square of the RPM speed. This means that if the speed is doubled, for example, the design load is increased by a factor of 4. This relationship is shown graphically below for one particular rod and piston.



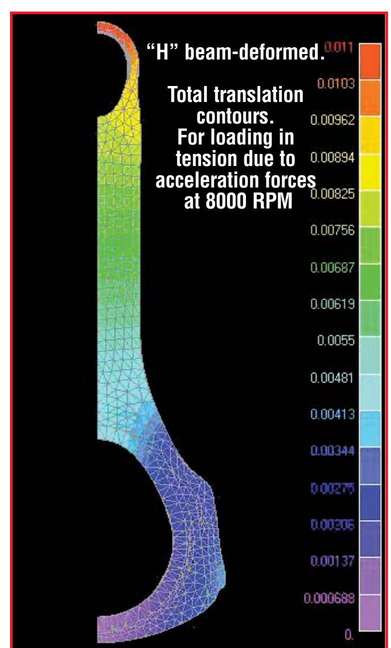
A typical value for this reciprocating weight is in the vicinity of 20,000 lbs. For purposes of bolt design, a "rule of thumb" is to size the bolts and select the material for this application such that each of the 2 rod bolts has a strength of approximately 20,000 lbs. (corresponding to the total reciprocating weight). This essentially builds in a nominal safety factor of 2. The stress is calculated according to the following formula:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{\text{Recip.Wt.}}{\frac{\pi}{4}D^2}$$

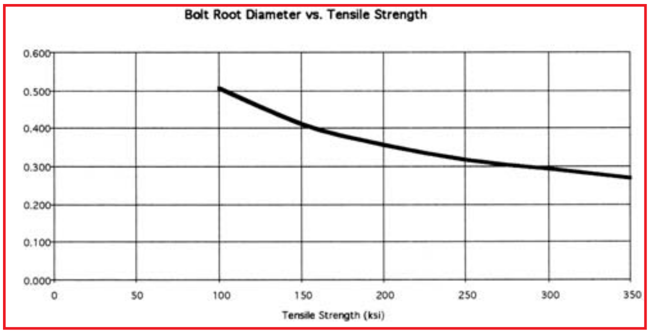
so that the root diameter of the thread can be calculated from the formula:

$$D = \sqrt{\frac{4 \times \text{Recip.Wt.}}{\pi \times \text{Allowable Stress}}}$$

This formula shows that the thread size can be smaller if a stronger material is used. Or, for a given thread size, a stronger material will permit a greater reciprocating weight. The graph *(see page 14)* shows the relationship between thread size and material strength.



It must be realized that the direct reciprocating load is not the only source of stresses in bolts. A secondary effect arises because of the flexibility of the journal end of the connecting rod. The reciprocating load causes bending deformation of the bolted joint (yes, even steel deforms under load). This deformation causes bending stresses in the bolt as well as in the rod itself. These bending stresses fluctuate



from zero to their maximum level during each revolution of the crankshaft.

The next step is to establish the details of the geometric configuration. Here the major consideration is fatigue, the fracture that could occur due to frequent repetition of high stresses, such as the bending stresses described above. Several factors must be considered in preventing fatigue; attention to design details is essential.

Fatigue failure is frequently caused by localized stress risers, such as sharp corners. In bolts, this would correspond to the notch effect associated with the thread form. It is well known that the maximum stress in an engaged bolt occurs in the last engaged thread. By removing the remaining, non-engaged threads, the local notch effect can be reduced. This leads to the standard configuration used in most ARP rod bolts: a reduced diameter shank and full engagement for the remaining threads. Providing a local fillet radius at the location of the maximum stress further reduces the local notch effect. Thus this configuration represents the optimum with respect to fatigue strength.

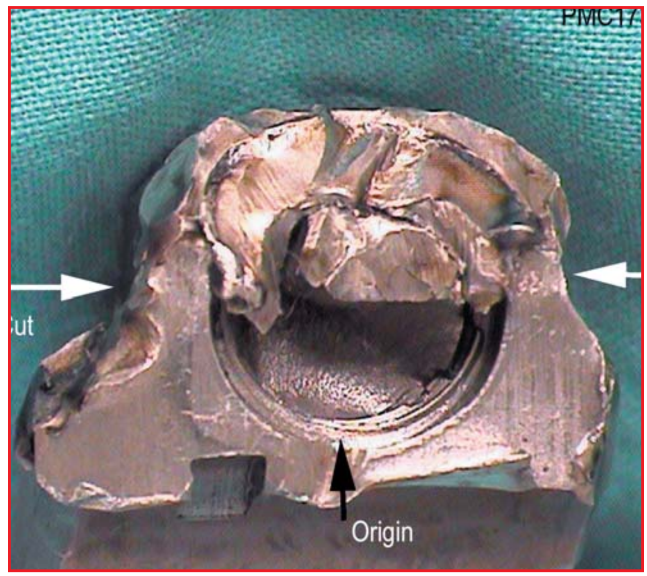
The reduced diameter shank is helpful in another sense. It reduces the bending stiffness of the bolt. Therefore, when the bolt bends due to deformation of the connecting rod, the bending stresses are reduced below what they would otherwise be. This further increases the fatigue resistance of the bolt. A typical bolt configuration is shown below.

Once the bolt configuration has been established, the manufacturing process comes into play. This involves many facets, which are discussed in detail elsewhere. Here, however, one process is of primary interest. With respect to bolt fatigue strength, thread rolling is a major consideration. Threads are rolled after heat treating. This process, which deforms the metal, produces a beneficial compressive stress in the root of the thread. It is beneficial because it counteracts the fluctuating tensile stresses that can cause fatigue cracking. If heat-treatment were to occur after rolling, the compressive stresses would be eliminated. This would therefore reduce the fatigue resistance of the bolt.

An additional factor must be taken into account in defining the bolt configuration: the length of engaged thread. If too few threads are engaged, the threads will shear at loads that are lower than the strength of the bolt. As a practical matter, the thread length is always selected so that the thread shear strength is significantly greater than the bolt tension strength.

This problem is especially important in bolts used in aluminum rods because of the fact that the shear strength of aluminum is much lower than the shear strength of steel.

Finally, although not a design parameter, the subject of bolt installation preload must be addressed. It is a fundamental engineering concept that the force in a bolt in an ideal preloaded joint will remain equal to the preload until the externally applied force exceeds the preload. Then the force in the bolt will be equal to the external force. This means that fluctuating external forces will not cause fluctuating forces in a preloaded bolt as long as the preload exceeds the external force. The result is that fatigue failure will not occur. In a non-ideal joint, such as in a connecting rod, the bolt will feel fluctuating stresses due to fluctuating rod distortions. These are additive to the preload, so that fatigue could result. In connecting rods, precise preloads are required because if they are too low, the external forces (the reciprocating weights) will exceed the preloads, thus causing fatigue. If they are too high,



they provide a high mean stress that combines with the fluctuating stresses due to rod distortion. Again, fatigue is promoted. The objective, then, is to preload a bolt so that it just exceeds the external load, and no higher. To sum up: both insufficient preloads and excessive preloads can lead to fatigue failures.

Appropriate preloads are specified for each ARP bolt. These preloads can be attained in a connecting rod by applying proper torque using a torque wrench or by measuring the amount of stretch in the bolt using a stretch gauge (it is known that a bolt stretches in proportion to the tension in it). The torque method is sometimes inaccurate because of the uncertainty in the coefficient of friction at the interface between the bolt and the rod. This inaccuracy can be minimized by using the lubricant supplied by ARP.

Other factors, equally as important as design, include material selection, verification testing, processing, and quality control. These aspects of bolt manufacturing are discussed elsewhere in this document.

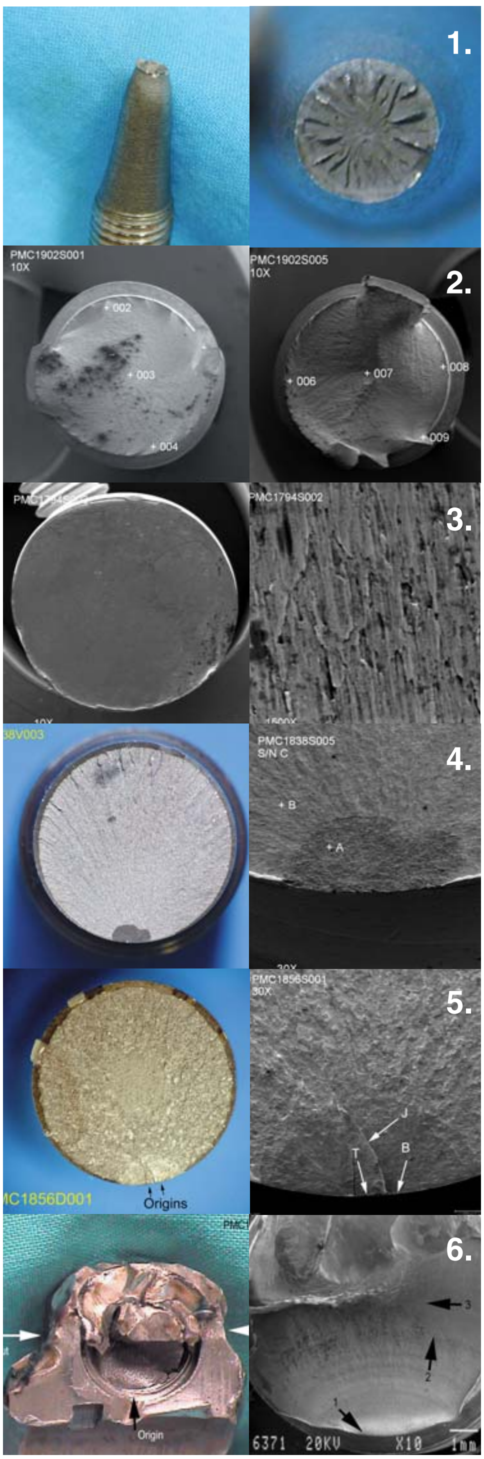
The foregoing discussion concentrated on the design of bolts. The same considerations apply in the design of studs.

Recognizing Common Failures

There are six types of metallurgical failures that affect fasteners. Each type has unique identifying physical characteristics. The following chart is designed to be used like a spark plug reading chart to help analyze fastener failures. While few of us have access to sophisticated analysis equipment, a standard Bausch and Lomb three lens magnifying glass will generally show 98% of what we want to see. Several of the photos below have been taken utilizing a Scanning Electron Microscope (SEM) and are presented to simply illustrate typical grain configurations after failure.

1. Typical Tensile Overload

In a tensile overload failure the bolt will stretch and "neck down" prior to rupture. One of the fracture faces will form a cup and the other a cone. This type of failure indicates that either the bolt was inadequate for the installation or it was preloaded beyond the material's yield point.



2. Torsional Shear (twisting)

Fasteners are not normally subjected to torsional stress. This sort of failure is usually seen in drive shafts, input shafts and output shafts. However we have seen torsional shear failure when galling takes place between the male and female threads (always due to using the wrong lubricant or no lubricant) or when the male fastener is misaligned with the female thread. The direction of failure is obvious and, in most cases, failure occurs on disassembly.

3. Impact Shear

Fracture from impact shear is similar in appearance to torsional shear failure with flat failure faces and obvious directional traces. Failures due to impact shear occur in bolts loaded in single shear, like flywheel and ring gear bolts. Usually the failed bolts were called upon to locate the device as well as to clamp it and, almost always, the bolts were insufficiently preloaded on installation. Fasteners are designed to clamp parts together, not to locate them. Location is the function of dowels. Another area where impact failures are common is in connecting rod bolts, when a catastrophic failure, elsewhere in the engine (debris from failing camshaft or crankshaft) impacts the connecting rod.

4. Cyclic fatigue failure originated by hydrogen embrittlement.

Some of the high strength "quench and temper" steel alloys used in fastener manufacture are subject to "hydrogen embrittlement." L-19, H-11, 300M, Aeromet 100 and other similar alloys popular in drag racing, are particularly susceptible and extreme care must be exercised in manufacture. The spot on the first photo is typical of the origin of this type of failure. The second is a SEM photo at 30X magnification.

5. Cyclic fatigue cracks propagated from a rust pit (stress corrosion)

Again, many of the high strength steel alloys are susceptible to stress corrosion. The photos illustrate such a failure. The first picture is a digital photo with an arrow pointing to the double origin of the fatigue cracks. The second photograph at 30X magnification shows a third arrow pointing to the juncture of the cracks propagating from the rust pits. L-19, H-11, 300M and Aeromet 100, are particularly susceptible to stress corrosion and must be kept well oiled and never exposed to moisture including sweat. Inconel 718, ARP 3.5 and Custom age 625+ are immune to both hydrogen embrittlement and stress corrosion.

6. Cyclic fatigue cracks initiated by improper installation preload

Many connecting rod bolt failures are caused by insufficient preload. When a fastener is insufficiently preloaded during installation the dynamic load may exceed the clamping load resulting in cyclic tensile stress and eventual failure. The first picture is a digital photo of such a failure with the bolt still in the rod. The arrows indicate the location of a cut made to free the bolt. The third arrow shows the origin of the fatigue crack in the second picture – an SEM photo at 30X magnification that clearly shows the origin of the failure (1), and the telltale "thumbprint" or "beach mark" (2). Finally (3) tracks of the outwardly propagating fatigue cracks, and the point where the bolt (unable to carry any further load) breaks-away.

The following material is intended to provide a brief overview of the metallurgical considerations that, daily, influence the design and production of the most reliable fasteners in motorsports. It is hoped that a simple understanding of the knowledge and commitment required to produce this reliability will make your future fastener decisions much, much easier.

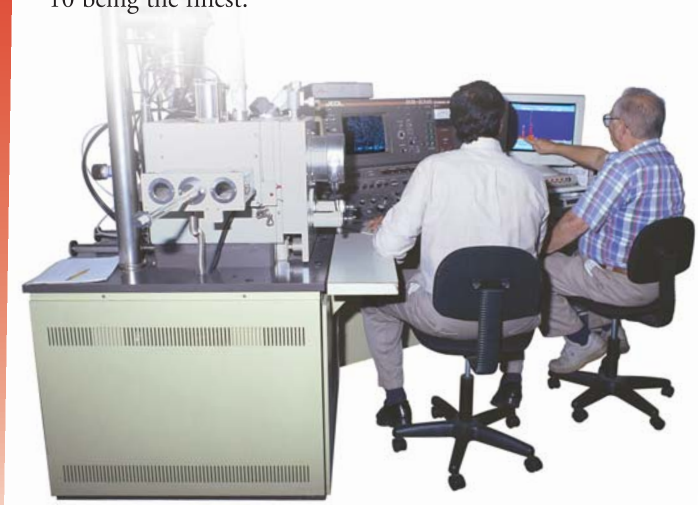
Metallurgy for the Non-Engineer

By Russell Sherman, PE

Metallurgist, Russell Sherman, PE, and stress/dynamics engineer Dr. Kenneth Foster, PhD, are the heart of ARP's technical power team.

1. What is grain size and how important is it?

Metals freeze from the liquid state during melting from many origins (called allotropic) and each one of these origins grows until it bumps into another during freezing. Each of these is a grain and in castings, they are fairly large. Grains can be refined (made smaller); therefore, many more of them can occupy the same space, by first cold working and then by recrystallizing at high temperature. Alloy steels, like chrome moly, do not need any cold work; to do this – reheat treatment will refine the grain size. But austenitic steels and aluminum require cold work first. Grain size is very important for mechanical properties. High temperature creep properties are enhanced by large grains but good toughness and fatigue require fine grain size-the finer the better. (High temp creep occurs at elevated temperature and depending on material and load could be as much as .001 per inch/per hour.) All ARP bolts and studs are fine grain – usually ASTM 8 or finer. With 10 being the finest.



ARP engineers use "Scanning Electron Microscopic" inspection capable of detecting all elements in the periodic table with atomic numbers greater than 5 – permitting the acquisition of high resolution imaging.

2. How do you get toughness vs. brittleness?

With steels, as the strength goes up, the toughness decreases. At too high a strength, the metal tends to be brittle. And threads accentuate the brittleness. A tool steel which can be heat-treated to 350,000 psi, would be a disaster as a bolt because of the threads.

3. Define Rockwell as we use it. Why do we use the C scale?

The man's name was Rockwell and he developed a means of measuring hardness of metals which was superior to other methods. A Rockwell hardness tester measures the depth of penetration into the metal when a load is applied. For hard materials, a diamond penetrator is used. For soft material, small balls are used – 1/16" or 1/8″ diameter-and the machine measures the depth. We use the C scale for the 120,000 psi strength level and above. The C scale uses the greatest load – 150 Kg. The A scale uses only a 60 Kg. load but can be correlated with C. It is necessary to use the A scale for thin sheets because using the 150 Kg load would cause the diamond to penetrate almost all the way through.

4. What is "micro hardness?"

Some parts are too small to be Rockwell hardness tested. They are placed in hard plastic and a microscope is used to place a small indenter into the metal. Using the microscope the length of the impression is measured.

5. How does modulus of elasticity refer to our products?

The modulus of elasticity of all alloy steels is exactly the same – 30,000,000 psi. This is true whether it is heat-treated or not – whether it is 100,000 psi strength level or 300,000 psi. Metals are like a spring – put a load on them and they will stretch – double the load and they will stretch double. This is important in connecting rod bolts because by measuring the stretch we really are measuring the load. Load is what is important and measuring stretch of a given size and configuration bolt will indicate how much load is stretching the bolt.

6. What are metal carbides and what is their significance?

The strength of all alloy and carbon steels is derived from the metal carbides formed during the mill processing. The carbon in steels combines with iron, vanadium and with chromium, as well as many other metal alloy additions to form compounds, which are a very hard phase within the iron matrix. Tool steels generally have high carbon content (above .8%) and can be made very hard – but brittle.

7. What exactly is chromium?

Chromium is a metal and is typically used for plating because it is shiny. It is also used as an alloy addition to iron to form a stainless steel. A stainless steel must contain at least 12% chromium, but these lean chromium steels can still show some rust on the surface. Using 18% chromium will make a more rust resisting stainless. Exposing any stainless to oxygen at temperatures above 1200°F will cause the chromium to join the oxygen and therefore leave the surface depleted in chromium if it falls below 12% the surface will show rust.

8. What does it mean when a broken part looks crystallized?

When the fracture face has a rocky appearance it is because the material had a very large grain structure. Basically the grain grew during manufacturing due to poor technique and handling. A properly processed part will have a silky smooth appearance which is an indication of fine grain size. So crystallization does not occur as a result of load or fatigue – it was present in the material at the time of manufacture.

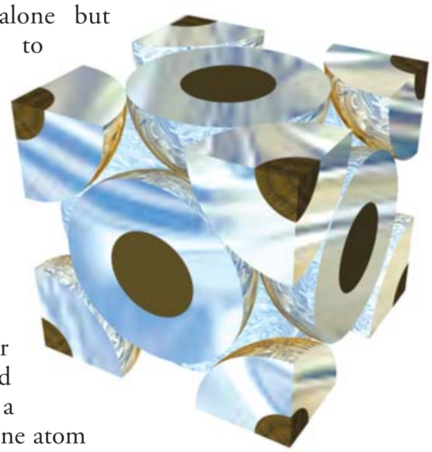
9. Define "precipitation hardening" and "phase change."

The precipitation hardening comes from microscopic precipitation of hard phases which serve to keep rows of atoms from moving under stress. Some metals undergo a change in atomic structure at high temperature. Alloy steels, which are bcc at room temperature, become fcc at temperatures above 1400°F. This switch over is called a phase change. When cooled down they revert back to the bcc structure. Management of this phase is extremely critical and ARP maintains a complete in-house heat-treatment facility. It's the only way we can assure material integrity.

10. What does a "face centered cubic" (fcc) atom arrangement look like? How many atoms?

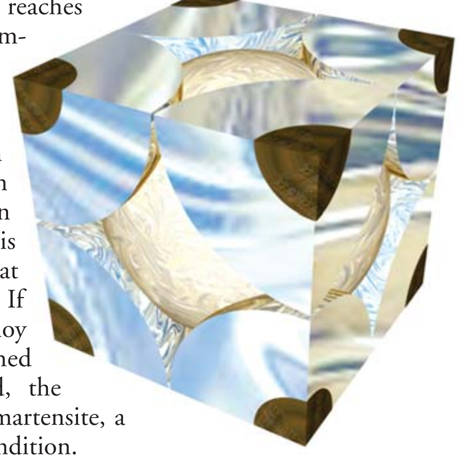
A face centered cubic arrangement of atoms (austenitic) looks like a Las Vegas die with a five showing on all six faces. This can't be seen visually by any type of microscope.

The number of atoms in any one cubic cell would be 14 – these do not stand alone but are attached to other cells which share some of the atoms.



11. How does a "body center cubic" (bcc) atom look? How many atoms?

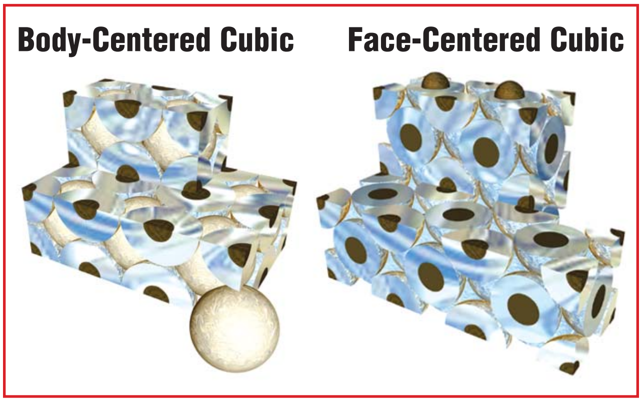
The body center cubic structure would look like a die with a four on all faces and one atom in the center of the cube. The atomic arrangement of pure iron is bcc at room temperature and does not change until the temperature reaches 1674°F. At this temperature it changes to austenite which is face center cubic (fcc). The addition of carbon to the iron lowers this transition temperature. This is the basis for heat treatment of steel. If the iron carbon alloy (steel) is quenched from the fcc field, the structure becomes martensite, a very hard strong condition.



12. What does a "stainless steel" atom arrangement look like? How many atoms?

A face centered cubic arrangement of atoms Stainless Steel 300 series is not heat-treatable. But heavy reduction (power dumping), in the cross section, during forging causes a dramatic increase in strength. This is the process ARP uses to make 304 Stainless Steel reach 170,000 psi UTS.

13. How do the space lattice or crystal structures appear?

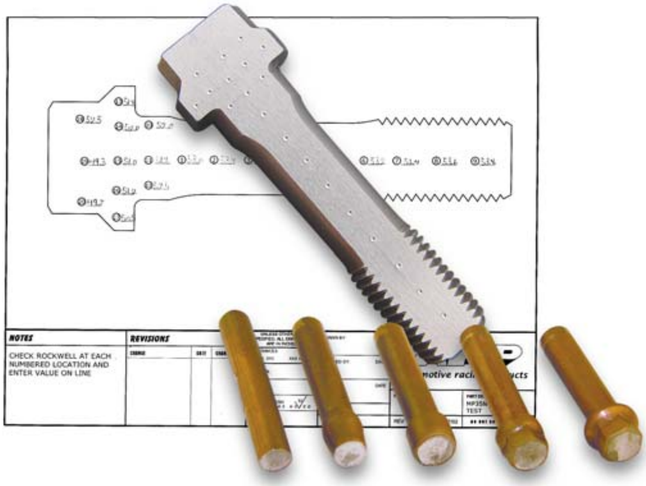


All grains or crystals are composed of atoms bound together in a definite pattern. These structures are called space lattice or crystal structures. At a fixed temperature, the atoms in an array are spaced a definite distance from one another, although they vibrate about their mean position. Even though atoms are actually not held together in this manner, it is helpful to picture the crystals as a 3-dimensional latticework connected by imaginary lines. Metallurgists who primarily study ferrous metal are interested in only two basic crystal structures: bcc (body-centered cubic) and fcc (face-centered cubic).

14. What are the metallurgical ramifications of "cold heading" vs. "hot heading?"

Cold heading is a more efficient process and allows the part to be cold worked. The temperatures used for hot forging will reduce the effect of work hardening. This is important for metals which derive much of their strength from the cold work. Cold heading produces a better product than hot heading. The number and force of the blows of the cold heading machine can make a significant difference in the quality of the end product. Excessive numbers of blows can lead to voids in the bolt head. ARP, in fact, holds significant patents on cold heading procedures for the higher nickel and cobalt based alloys.

Our patented process begins with a softer wire that can be cold forged. The process work hardens the head and the under head area to the desired hardness. We then power extrude the front end to achieve the reduction and hardness in the shank



resulting in a bolt with even strength and hardness from end to end.

In a typical aerospace manufacturing process, these alloys are hot headed from bars, reduced in diameter from 48 to 50 % by cold drawing, resulting in a hardness of about Rockwell C46 which is too hard for cold heading. So, the blanks are locally induction heated in a very narrow temperature envelope and hot headed. The process reduces the hardness immediately in the area under the head approximately 3 to 5 points on the Rockwell C scale. Subsequent heat treatment does not restore this partially annealed area to full hardness and strength. The final result is a relatively soft-headed bolt. Therefore, this process is not used by ARP.

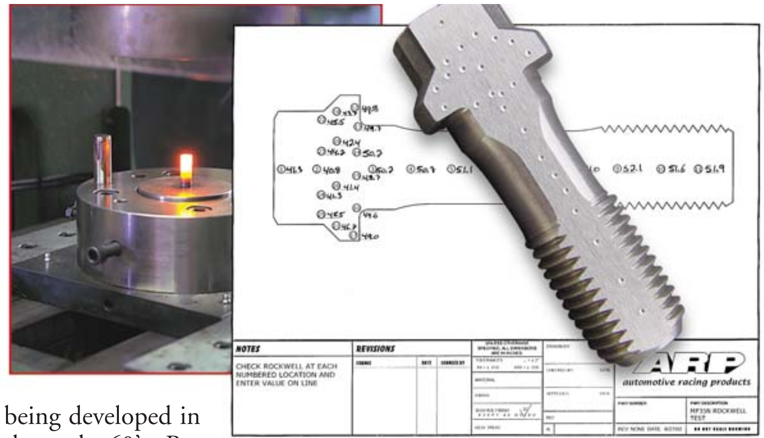
15. What is the difference between the usage of "bar" material vs. "wire?"

Bars produced by the mill in straight sections are normally shipped in 12 foot lengths. Wire is supplied in continuous coil form and is hundreds of feet in length. Bars are cut to length and the bolts are hot forged from these lengths. Wire on the other hand is fed into a cold header in a continuous manner.

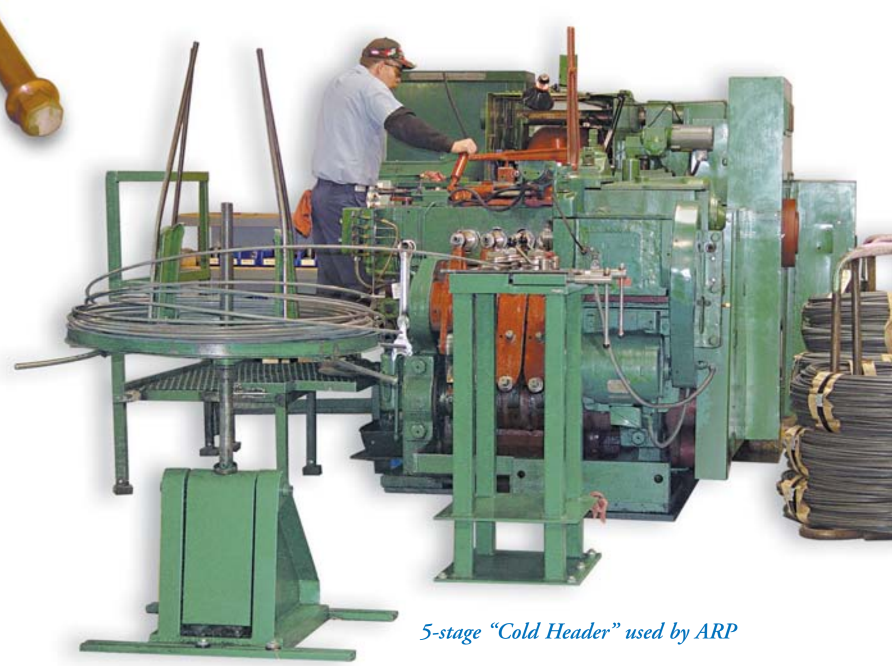
16. What exactly is A286? And to what is it compared?

A286 is a 25% nickel and 18% chromium alloy with smaller amounts of titanium and aluminum, which precipitate during aging – after solution treatment. It is a true stainless steel due to the high chromium and it is austenitic due to the high nickel. A286 was developed as a high temperature alloy for use in pre-jet aircraft engines. The strength level was only 140,000 psi, but it had good high temperature strength and exceptional toughness, making it an excellent fastener alloy.

Rocketdyne became interested in it for rocket engines



being developed in the early 60's. But they required higher strength. We were part of the team that developed a thermo-mechanical method to produce a strength level of 200,000 psi. This involved severe cold reduction after solution treatment and before aging. An aerospace material spec (AMS) was then written requiring this treatment for 200,000 psi strength level. There is no other steel alloy, at this level, which can match A286 for corrosion resistance, toughness or bolt fatigue strength.



5-stage "Cold Header" used by ARP

17. Define "Power Dump."

This is a term used to define the heavy extrusion of the fastener body during forging. The part is forced into a die much smaller than the blank thereby causing a severe reduction in cross section area. This reduction of the cross sectional area is accompanied by an increase in length because metals can't be compressed. However, power dumping or reduction, delivers a significant increase in strength properties and is part of the patented process we use to produce fasteners from 304 stainless steel with 170,000 psi UTS and AMS 5844 (ARP 3.5) with ultimate tensile strengths in the 270,000 psi UTS range with outstanding fatigue.

18. What is the difference between 4130 and 8740 chrome moly?

Both are alloy steels with similar chemistry. The 4130 has only .3% carbon and can't be hardened as high as 8740, which has .4% carbon. Also, 8740 has about .45% nickel and 4130 has none. Both have moly (most alloy steels have moly). The chromium content of 4130 is slightly higher, .95% instead of .55%. However, 8740 is generally considered to have slightly better toughness due to the nickel.

19. What exactly is ARP2000 and how does it compare to 8740 and 4340?

ARP2000 is a heavily alloyed martensitic quench and temper steel, initially developed for use in steam power plants. As such it has excellent stability at high temperatures. But most important, ARP research discovered that in addition to temperature stability it has excellent notch toughness in the higher strength ranges and is alloyed to be tempered to Rc44/47. 8740 and 4340 can be tempered to the same hardness. But, the tempering temperature would yield material in the “temper brittle zone” (between 500° and 700°F), producing significant notch sensitivity. ARP2000 is tempered above that temperature range and has a strength between 200,000 and 220,000 psi.

20. How does L19 compare to ARP2000?

L19 differs from ARP2000 in that it is a vacuum melted alloyed steel with sufficient chromium and carbon to achieve high hardness (but below the level of a stainless steel). L19 is air-cooled from the hardening temperature in a way that does not require an oil quench to achieve full hardness and is tempered to assure full conversion to martensite between 1025°F and 1075˚F. L19 is a proprietary material capable of achieving strengths of 220,000/230,000 or 260,000/270,000 psi as may be required. Both L19 and ARP2000 steels are modified bcc (martensite) at room temperature. L19 has the same advantage as ARP2000 in that a high strength is obtained at a high tempering temperature. This alloy is easily contaminated and requires special handling.

21. What is AMS5844? And how does it compare to AMS5842E?

Both of these alloys are considered multiphase, non-steel, austenitic materials. Both derive their strength (260,000 psi) from severe cold work (48/50%) which raises the hardness from Rockwell C 46 up to 49/50. The AMS5842 (for MP159) was developed much later than AMS5844 (for MP35) in order to increase the usable service temperature by about 100° so it could be used in hotter sections of jet engines.

22. Provide a brief overview of the metallurgy required to produce AN, AMS & other Aerospace type fasteners.

All alloy steel fasteners are essentially manufactured by the same process. Incoming steel from the mill is forged to specification, then heat treated and thread rolled. Regular AN bolts are forged to size and are normally not precision ground. They may even have threads on them when heat treated.

Expensive aerospace fasteners are more likely suited for some motorsport applications. These fasteners require precision forging, careful heat treatment and then precision grinding, fillet rolling under the head and a great deal of skill in thread rolling.

23. What is moisture tolerance and how or where is it important?

Non-stainless steels have low moisture tolerances because the water attacks the steel by forming iron oxide (rust). Therefore none of these have a high tolerance for moisture and the surface must be protected by oil or plating. ARP maintains an in-house plating facility to assure all non-stainless product is delivered 100% corrosion free.

24. How do the various standards compare to each other with regard to fasteners? Where are the standards?

A standard fastener is one that can be referenced from a nationally or internationally recognized standards document and may be produced by any interested manufacturer.

In all fastener categories the custodian of each group (MS-AN-NAS) have tried to standardize the processing of specifications such as AS (American Standard) heat-treating, MIL-H-6875 cadmium plating, AMS QQ-P-416 passivation and AMS QQ-P-35 testing, MIL.-Std 1312 and NDT in aerospace applications are generally by sample.

ASTM stands for the American Society for Testing Materials, a large industry funded group used to write standards for many materials and testing procedures. It compares directly to **AMS (Aerospace Material Standard)**.

In the case of ARP, 100% raw material is purchased to AMS specification – with the exception of special alloys used in proprietary products. All materials are carefully examined for proper chemistry – and finally, periodic examination by an independent laboratory. ARP consistently strives to exceed industry specifications for quality and product management.

MS (Military Standards): MS bolt specifications cover a wide range of fastener hardware, high strength bolts, nuts and washers with spec’s for materials and processing. MS fasteners have various tensile strengths.

AN (Army-Navy) Specifications: Generally lower strength bolts and studs primarily in the 125 psi UTS range. AN also covers a wide range of nuts, washers and other hardware.

NAS (National Aerospace Standard): These specifications cover fasteners in the strength ranges 160,000/180,000/200,000 psi UTS.

ISO (International Standards Organization):

ISO 9001-94: is a quality control system designed for manufacturers with design control.

ISO 9002-94: is a quality control system designed for manufacturers who build parts to customer specifications, and do not have design control.

ISO 9001-2000: is current ISO system well suited for manufacturers with engineering design functions, drawing control and statistical techniques to achieve demanding quality requirements.

This system is the main focus of ARP’s World Quality Concept.

25. What metallurgical issues cause common failures?

The most common cause of failure of connecting rod bolts (and wheel bolts) is too little induced load (stretch) during installation. This allows the alternating load to impose cyclic loading on the bolt. Over tightening is also another cause, because the induced stress is too close to the yield point.

MATERIAL SPECIFICATIONS

ARP manufactures fasteners from a wide assortment of materialsranging from popular stainless steel and 8740 chrome moly to exotic alloys that have been developed to handle space travel. You should also know that there are grades within specific alloys. For example, 8740 is available in four grades: 1. SDF (guaranteed seamless and defect free). 2 CHQ (cold head quality). 3. Aircraft. 4. Commercial. ARP uses only the first two (SDF and CHQ), even though they cost more than double "Aircraft" quality.

STAINLESS STEEL: Ideally suited for many automotive and marine applications because stainless is tolerant of heat and virtually impervious to rust and corrosion. ARP "Stainless 300" is specially alloyed for extra durability. It's polished using a proprietary process to produce a beautiful finish. Tensile strength is typically rated at 170,000 psi.

8740 CHROME MOLY: Until the development of today's modern alloys, chrome moly was popularly considered a high strength material. Now viewed as only moderate strength, 8740 chrome moly is seen as a good tough steel, with adequate fatigue properties for most racing applications, but only if the threads are rolled after heat-treatment, as is the standard ARP production practice. Typically, chrome moly is classified as a quench and temper steel, that can be heat-treated to deliver tensile strengths between 180,000 and 210,000 psi.

ARP2000®: An exclusive, hybrid-alloy developed to deliver superior strength and better fatigue properties. While 8740 and ARP2000 share similar characteristics – ARP2000 is capable of achieving clamp loads in the 215,000-220,000 psi range. ARP2000 is used widely in short track and drag racing as an up-grade from 8740 chrome moly in both steel and aluminum rods. Stress corrosion and hydrogen embrittlement are typically not a problem, providing care is taken during installation.

L19: This is a premium steel that is processed to deliver superior strength and fatigue properties. L19 is a very high strength material compared to 8740 and ARP2000 and is capable of delivering clamp loads in the 230,000-260,000 psi range. It is primarily used in short track and drag racing applications where inertia loads exceed the clamping capability of ARP2000. Like most high strength, quench and temper steels – L19 requires special care during manufacturing to avoid hydrogen embrittlement. This material is easily contaminated and subject to stress corrosion. It must be kept well-oiled and not exposed to moisture.

AERMET® 100: With a typical tensile strength of 280,000 psi, Aermet 100 is a new martensitic super-alloy that is stronger and less expensive than the super-alloy austenitic materials that follow. Because it is capable of achieving incredibly high clamping loads, it is ideal for short but extreme environments like top fuel, funny car and some short track applications. Although Aermet 100 is a maraging steel that is far superior to other high strength steels in its resistance to stress corrosion, it must be kept well-oiled and not exposed to moisture.

INCONEL 718: A nickel based material that is in the high temperature, super-alloy class, it is found to be equally suitable in lower temperature applications. This material delivers tensile strengths into the 220,000 psi range and exhibits improved fatigue properties. Best of all, Inconel 718 is completely immune to hydrogen embrittlement and corrosion.

ARP3.5® (AMS5844): While similar to Inconel 718, these super-alloys are found in many jet engine and aerospace applications where heat and stress attack the life of critical components. The high cobalt content of this alloy, while expensive, delivers a material with superior fatigue characteristics and typically tensile strength in the 270,000 psi range. The immunity to hydrogen embrittlement and corrosion of these materials is a significant design consideration. These materials are primarily used in connecting rods where extremely high loads, high RPM and endurance are important factors – Formula 1, Winston Cup and CART applications.

CUSTOM AGE 625 PLUS®: This newly formulated super-alloy demonstrates superior fatigue cycle life, tensile strength and toughness – with complete resistance to atmospheric corrosion and oxidation. ARP is the first to develop manufacturing and testing processes for fasteners with Custom Age 625+. Best of all it is less expensive and expected to soon replace MP-35 as the material of choice in the high strength, super-alloy field. Typical tensile strength is 260,000 psi.

TITANIUM: ARP now offers special order fasteners made of an alloy (Ti6Al-4V) that is specially heat-treated (a process developed by ARP's own Russ Sherman) and provides superior strength to other titanium alloys employed in racing and aerospace. The material has a nominal tensile strength of 180,000 psi, and is very corrosion resistant. The main advantage of titanium, of course, is its weight – which is about 40% lighter than a comparable fastener made of steel. Head studs and accessory bolts are ideal applications for this lightweight material.

QUICK REFERENCE GUIDE TO MATERIALS USED IN FASTENERS

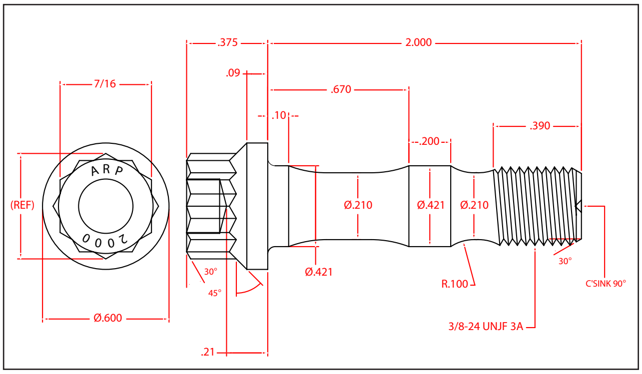
MATERIAL	USE?	YIELD STRENGTH	TENSILE STRENGTH	USED FOR
Grade 5	**No**	90,000 psi	120,000 psi	Accessory bolts and studs
Grade 8	**No**	120,000 psi	150,000 psi	Accessory bolts and studs
"Stainless 300"	Yes	140,000 psi	170,000 psi	Accessory bolts & studs, head studs
Custom 450®	Yes	150,000 psi	180,000 psi	Head bolts, accessory bolts
8740 chrome moly	Yes	160,000 psi	190,000 psi	Rod bolts, head & main studs & bolts
A286	Yes	170,000 psi	200,000 psi	Head bolts, accessory bolts
ARP2000	Yes	180,000 psi	215-220,000 psi	Connecting rod bolts
L19	Yes	200-230,000 psi	230-260,000 psi	Connecting rod bolts
Inconel 718	Yes	190-210,000 psi	220-240,000 psi	Connecting rod bolts
Custom Age 625+®	Yes	235-255,000 psi	250-280,000 psi	Head studs, connecting rod bolts
ARP 3.5	Yes	220-250,000 psi	250-280,000 psi	Connecting rod bolts
AerMet® 100	Yes	258,500 psi	300,000 psi	Connecting rod bolts
Titanium	Yes	160,000 psi	180,000 psi	Head studs, accessory bolts

SPECIAL NOTE: The U.S. Government has implemented guidelines relating to rating fastener strength. Unless a specific fastener has been tested in a government approved independent lab, manufacturers are enjoined from using a specific rating. Even though, in the case of ARP, the very same equipment and testing procedures are used in-house. Rather than have expensive duplicate tests run on literally hundreds of part numbers, which would drive the cost of each fastener through the roof, ARP is following approved guidelines by using generalities to describe strength ratings.

YOU CAN GET ARP FASTENERS MADE TO YOUR REQUIREMENTS!

The following pages in this catalog detail the vast number of “off the shelf” fasteners available from ARP. However, it’s important for you to know that a significant amount of ARP’s business comes from the development and manufacture of custom fasteners. For example, many top Formula 1, CART and IRL race teams and constructors have come to rely on ARP for a myriad of special purpose fasteners. Many of these have been developed on a proprietary basis, and we cannot go into details about “what” is being manufactured for “whom” by ARP. But suffice to say that that ARP has established a reputation within the racing industry for doing cutting edge R&D and following it up with fasteners made to the most stringent quality control standards on the planet. ARP also “private labels” a number of special fasteners for various manufacturers in the performance industry.

8740 ARP2000 L19



ARP can custom manufacture fasteners from nearly a dozen different materials, with tensile strengths ranging from 170,000 PSI to over 300,000 psi. By way of example, we have made cylinder head studs for the same application from 8740 chrome moly, our own ARP2000 and L19.

The bottom line is that because of ARP’s extensive in-house R&D and manufacturing capabilities, the firm is in a position to design and build fasteners on a custom basis. Serious inquiries from members of the high performance industry are always welcome. Look to ARP to provide effective solutions to all your fastener needs!

Custom-Made ARP Titanium Studs & Bolts

One of ARP’s best-kept “secrets” is the company’s deep involvement in the manufacture of titanium fasteners. As a matter of fact, ARP’s resident metallurgist, Russ Sherman, literally “wrote the book” when he developed the original procedures for the heat treatment of the most popular titanium alloy in use today (Ti6Al-4V), and presented the research data to the American Society for Metals. Sherman’s procedure of solution-treating, warm processing and aging brings the titanium to strength levels never before achieved, and has also been instrumental in setting new standards for the aerospace industry.

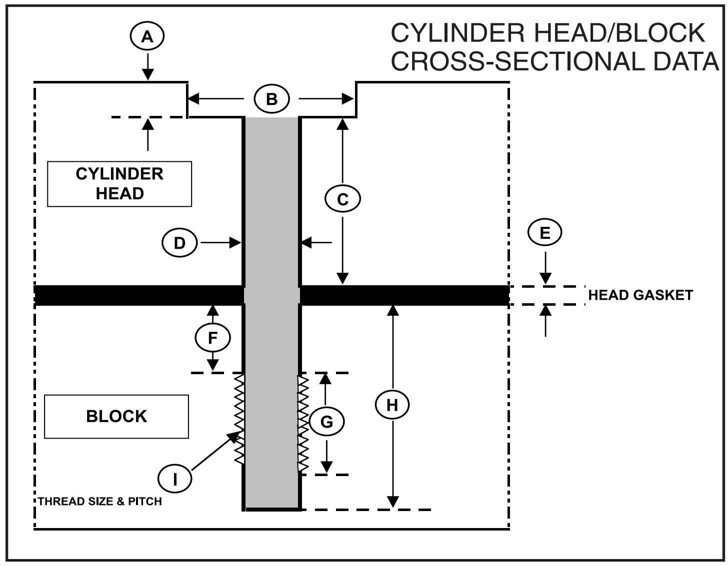
This particular titanium alloy and process lends itself well to a number of racing applications, including head studs and accessory fasteners. Of course, the primary advantage of using titanium instead of steel is weight; titanium is about 40% lighter. The material ARP uses has a tensile strength of 180,000 psi, comparable to heat-treated chrome moly – but about half the weight.

ARP stands ready to manufacture Ti6Al-4V titanium fasteners custom-made to your specifications. Contact our Special Projects Dept. at **805-525-1497**.

GETTING THE CORRECT ARP HEAD STUD/BOLT FOR THE APPLICATION

Today, there are literally dozens of different cylinder head and engine block combinations for the more popular applications, and new offerings coming out all the time. It is virtually impossible for ARP's engineering staff to obtain detailed information from all of these various sources, so it may be necessary for customers to calculate exactly what they have so the correct cylinder head studs or bolts are used. Whether it's a small block Chevy engine or a Honda VTEC, the procedure remains the same.

The illustration on the right shows the nine different variables that come into play when determining the proper fastener for a particular position. Many cylinder heads have different column heights, etc. at various positions, and additional variables come into play when using aftermarket engine blocks (some of which have "blind" tapped holes for attaching the heads that are shallower than OEM). It is therefore critically important that you determine exactly how many different bolt/hole combinations exist for the cylinder head installation.



You must have the following data:

A. Depth of cylinder head counter bore__________

B. Diameter (o.d.) of head counter bore __________

C. Column height (net thickness of head) __________

D. Diameter (o.d.) of bolt hole in block __________

E. Head gasket thickness (uncompressed) __________

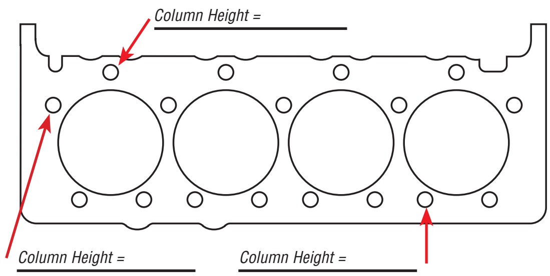
F. Depth of counter bore in block __________

G. Length of thread in block __________

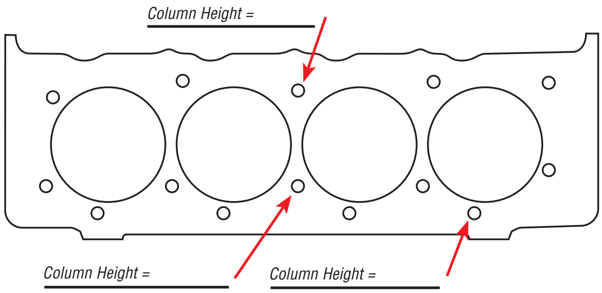
H. Depth of hole from surface to bottom __________

I. Thread size and pitch __________

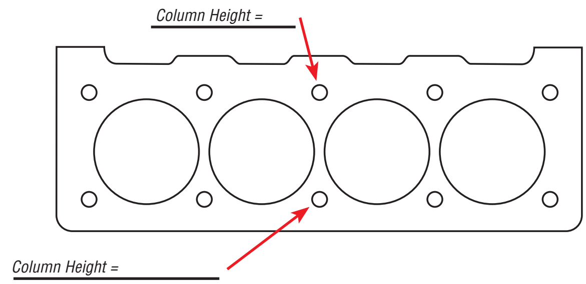
STANDARD SMALL BLOCK CHEVROLET

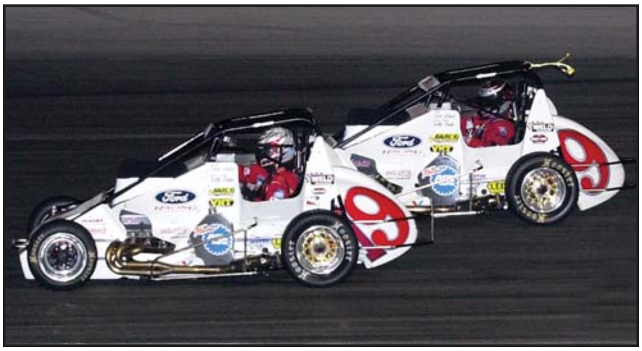


STANDARD BIG BLOCK CHEVROLET



CHRYSLER, FORD & MOST 4-CYLINDER





The 9 Racing, Inc. midgets have nine USAC championships.

David Rampy - Competition Eliminator standout and all-time leader.

GLOSSARY OF TECH TERMS

Austenitic: Refers to the atomic arrangement of some metals, such as nickel based alloys, and some steels with about 18% chromium. This atomic arrangement is called "face centered cubic." Austenitic steels can not be heat treated, but can be strengthened by cold working.

CHQ: A term used to grade heading wire and stands for "cold heading quality." This grade is superior to both Commercial and Aircraft quality.

Clamp Load: This is the force exerted by a tightened bolt and is the same as preload.

Fatigue: The process by which failure is caused after many repetitions of loads smaller than the ultimate strength of the material.

Ferritic: Refers to steels with an atomic arrangement different from austenite and martensite. These steels are not strong and the widest use is in steam power plants and accessory fasteners made by some companies, because they are able to withstand wet environments. Newer steels such as ARP300 and A286 are far superior.

Hydrogen Embrittlement: This condition results from the accumulation of hydrogen gas in the atomic structure of the metal. This gas flows to the point of high stress (stress risers) and causes microscopic cracks. The hydrogen then flows to the "new" crack tip and causes it to crack further. In this way the crack moves across the part, because the crack-tip IS the stress riser. Finally the crack gets so large that the section is not large enough to support the load. No hydrogen embrittlement can take place without tensile stress. ARP employs a baking process that purges hydrogen gas from the steel.

Knurling: A process of creating serrations in a part by rolling a die, under pressure, against the part. Normally these serrations are very sharp and can create cracks and ARE stress risers. The process is used on knobs so the user can get a firm grip. But in the case of fasteners, the body can be knurled so the part can be forced into and retained in an irregular hole – stress risers and all.

Maraging: Refers to steels that are a low carbon version of martensitic steels, specially alloyed so that the martensite is not hard. These steels can be worked in the quenched condition and then be hardened by low temperature aging. The strength comes from the formation of complex metal carbides.

Martensitic: Refers to atomic arrangement and in the case of steels, is a modified body centered cubic structure. These steels can be heat-treated because martensite is iron carbide, which is very hard. However, these steels can be hydrogen embrittled and will rust. Generally, martensite normally refers to metal structures which are formed by quenching from high temperature.

MS21250: A military specification for a 12-point, 180,000 psi bolt which specifies the fatigue load required for testing every size.

Notch Sensitivity: Refers to the ability of a metal to withstand the increased stress at a notch. Some materials, such as glass, crack very easily if notched. While others, such as soft gold or tin stretch out under stress – even with a notch. Normally, the stronger the steel, the more likely it is to break quickly at the notch. "Toughness" is wanted because this is associated with opposite of notch sensitivity. Austenitic metals are usually less notch sensitive than martensitic steels of the same strength levels.

OAL: Means "Over All Length."

Preload: The force IN a bolt when it is installed with a torque greater than simply hand tight. Preload can be established by measuring torque or bolt stretch or by the less than accurate "turn-of-the-nut" method.

Qualified Products List: A government requirement that simply mandates that bolts be manufactured only by companies which have qualified by making bolts that have been submitted for testing and approval to a government agency. ARP has qualified for this list.

Quench & Temper: A method of heat-treating martensitic steels. The parts are heated into the austenitic range (usually above 1450°F) then quenched into water or oil. This leaves the part in a very hard martensitic condition which then must be tempered by heating at lower temperatures (between 350°F and 1200°F), depending upon the steel and strength desired.

Reciprocating Load: The acceleration force exerted on a connecting rod due to the up and down motion of the piston and its associated mass ie; wrist pin, rings, small end of the rod.

Stretch: The increase in length of a bolt when installed with a preload.

Stress: The load applied to a part divided by the cross-sectional area of the part, usually expressed in pounds per square inch (psi).

Stress Corrosion: This is a special form of hydrogen embrittlement in which the metal is attacked while under stress. Without the stress the crack will not move. But under stress the crack moves and corrosion takes place at the freshly opened crack face.

Stress Ratio: The ratio of the minimum stress to the maximum stress in a structure which is subject to fluctuating loads.

Stress Riser: You have a notch, ding or some change in section size, so now the stress at these points is increased above nominal stress. Compare this kind of stress to the flow of water in a river. When the river hits a narrow point it flows faster. Perhaps there is a rock in the middle – the river flows faster around the rock. The stress at these points can be so high that the part will fail – even though the average stress on the part never exceeded the tensile strength of the part.

S.D.F.: Seam and defect free. A designation for premium steel. This is typically the highest grade available, and is the only steel used by ARP.

Thread Engagement: This refers to the number of threads engaged in a nut or threaded hole. Full engagement, meaning all the female threads are engaged, is a desirable configuration to maximize fatigue strength.

Ultimate Tensile Strength: The maximum stress that a particular material can support without breaking. It is expressed in terms of lbs. per square inch, and is measured by means of a tensile test. The maximum force (lbs.) that a test specimen can support is divided by the cross-sectional area (square inches) of the specimen, the result is ultimate tensile strength in psi.

Torque Angle: A method of tightening a fastener relative to the amount of degrees turned once the underside of the bolt head or nut face contacts the work surface. This procedure is suitable for engine assembly only when the installation has been calibrated in terms of bolt stretch relative to the exact application (the amount of compression of the clamped components is critical).

UHL: Means "Under Head Length." The distance as measured from tip of the fastener to a place directly at the base of the head.

Yield Strength: The stress at which a given material or component exhibits a permanent deformation (i.e. "takes a set"). When the load that caused the stress is removed, the part will not return to its original dimensions. If you exceed the yield strength of a fastener (tighten it until it feels funny and then back it off a bit) the fastener is ruined and must be replaced.

FASTENER TORQUE RECOMMENDATIONS

Listed are the recommended torque values for most ARP fasteners. Recommended torque is equal to 75% of the fastener's yield strength. THE TORQUE VALUES REPRESENTED HERE ARE INTENDED TO BE FOR GENERAL INFORMATION, NOT FOR SPECIFIC INSTALLATIONS. In special instances, where supplied instructions deviate from the torque values recommended here, always follow the instructions. Simply read down to the correct fastener size, then across to find the torque value for your application. Stud torque values are based on the coarse thread yield strength and torque being applied to the fine thread i.e. (7/16-14 into the block and torque applied to 7/16-20 threaded nut). **NOTE: ALWAYS LUBRICATE FASTENERS PRIOR TO APPLYING TORQUE TO ENSURE ACCURATE READINGS.**

Recommended Torque to Achieve Optimum Preload (Clamping Force)
Using ARP Moly Assembly Lubricant or 30-wt. oil - Torque (ft./lbs.) - Preload (lbs.)

Note: For those using Newton/meters as a torquing reference, you must multiply the appropriate ft./lbs. factor by 1.356.

Thread Size and Type	Fastener Tensile Strength (PSI)								
	170,000/180,000 (1,171 N/mm^2)			190,000/200,000 (1,309 N/mm^2)			220,000 (1,515 N/mm^2)		
	Torque w/30 wt. oil *not recommended*	Torque w/ARP Moly	Preload	Torque w/30 wt. oil *not recommended*	Torque w/ARP Moly	Preload	Torque w/30 wt. oil *not recommended*	Torque w/ARP Moly	Preload
1/4˝ stud	12	10	3,804	14	11	4,280	15	12	4,755
1/4-20	13	10	3,804	14	11	4,280	16	13	4,755
1/4-28	14	11	4,344	16	13	4,887	18	14	5,430
5/16˝ stud	25	20	6,264	28	22	7,047	32	25	7,830
5/16-18	26	21	6,264	29	23	7,047	32	26	7,830
5/16-24	28	22	6,948	32	25	7,817	35	28	8,685
3/8˝ stud	45	35	9,276	50	39	10,436	56	44	11,595
3/8-16	46	36	9,276	51	41	10,436	57	45	11,595
3/8-24	50	39	10,512	57	44	11,826	63	49	13,140
7/16˝ stud	71	56	12,720	80	63	14,310	89	70	15,900
7/16-14	73	58	12,720	82	65	14,310	91	72	15,900
7/16-20	80	62	14,220	90	70	15,998	100	78	17,775
1/2˝ stud	108	84	16,992	122	95	19,116	135	105	21,240
1/2-13	111	88	16,992	125	99	19,116	138	110	21,240
1/2-20	122	95	19,164	137	107	21,560	152	119	23,955
9/16˝ stud	156	122	21,792	175	137	24,516	195	152	27,240
9/16-12	159	126	21,792	179	142	24,516	199	158	27,240
9/16-18	174	136	24,312	196	153	27,351	217	170	30,390
5/8˝ stud	214	167	27,072	241	187	30,456	268	208	33,840
5/8-11	220	174	27,072	247	196	30,456	275	217	33,840
5/8-18	243	189	30,660	273	212	34,493	303	236	38,325
6mm stud	10	9	2,900	–	–	–	–	–	–
6mm x 1.0	11	9	2,900	–	–	–	–	–	–
8mm stud	25	20	6,250	28	22	7,050	32	25	7,830
8mm x 1.25	25	20	6,250	28	22	7,050	–	–	–
10mm stud	54	42	10,600	70	60	12,015	68	53	13,350
10mm x 1.25	54	42	10,600	–	–	–	–	–	–
10mm x 1.50	50	38	9,500	–	–	–	–	–	–
11mm stud	80	63	14,220	90	71	15,998	100	79	17,775
12mm stud	97	77	15,540	109	86	17,483	122	96	19,425

ROD BOLT STRETCH & TORQUE SPECS

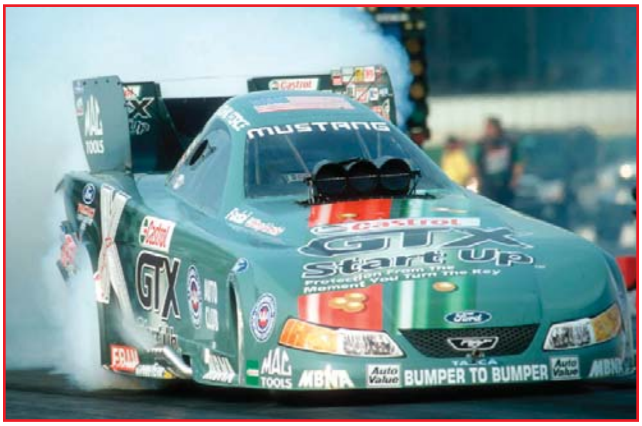
Make	Rod Bolt Part No.	Stretch (inches)	ARP Lube (ft./lbs.)
ALFA ROMEO	126-6101	.0080	45
AMC	112-6001	.0067	40
	114-6001	.0067	40
	114-6002	.0072	50
	114-6003	.0062	40
	114-6004	.0061	50
BMC/TRIUMPH	206-6001	.0067	50
	206-6002	.0067	35
	206-6003	.0067	44
	206-6004	.0061	44
	206-6005	.0060	42
	206-6006	.0067	50
	206-6007	.0048	30
BMW	201-6102	.0070	50
BUICK	123-6001	.0063	50
	123-6002	.0064	50
	124-6001	.0057	40
	125-6001	.0057	50
CHEVY	131-6001	.0062	40
	132-6001	.0062	40
	132-6002	.0057	25
	133-6001	.0064	50
	133-6002	.0068	40
	134-6001	.0062	40
	134-6002	.0061	50
	134-6003	.0063	50
	134-6005	.0063	50
	134-6006	.0055	45
	134-6401	.0062	40
	134-6402	.0066	50
	134-6403	.0063	50
	135-6001	.0080	75
	135-6002	.0063	50
	135-6401	.0080	75
	135-6402	.0064	50
	234-6301	.0064	40
	234-6401	.0070	40
	234-6402	.0055	45
	234-6403	.0065	50
	235-6401	.0075	60
	235-6402	.0070	45
	235-6403	.0075	60
CHRYSLER	141-6001	.0063	50
	141-6401	.0064	50
	142-6001	.0069	50
	142-6002	.0063	50
	144-6001	.0063	50
	144-6401	.0063	50

Make	Rod Bolt Part No.	Stretch (inches)	ARP Lube (ft./lbs.)
	145-6001	.0072	75
	145-6002	.0063	50
	145-6402	.0064	50
	244-6401	.0072	55
	245-6402	.0075	50
FORD	150-6004	.0063	50
	150-6005	.0063	50
	150-6404	.0064	50
	151-6001	.0065	40
	151-6002	.0065	40
	151-6003	.0050	26
	151-6004	.0055	22
	151-6005	.0049	36
	152-6001	.0071	50
	152-6002	.0063	50
	153-6001	.0069	30
	153-6002	.0063	32
	154-6001	.0063	50
	154-6002	.0069	30
	154-6003	.0063	50
	154-6004	.0055	50
	154-6005	.0063	50
	154-6402	.0069	28
	154-6403	.0064	50
	155-6001	.0063	50
	155-6002	.0063	50
	155-6003	.0063	50
	200-6001	.0045	60
	250-6404	.0063	50
	251-6201	.0047	30
	251-6301	.0061	44
	251-6402	.0065	38
	254-6402	.0070	25
	254-6403	.0065	45
	255-6402	.0062	40
HOLDEN	200-6506	.0067	70
	205-6001	.0063	50
HONDA	208-6001	.0055	26
	208-6401	.0077	40
MITSUBISHI	107-6001	.0060	40
	107-6002	.0069	37
	107-6003	.0068	35
	107-6004	.0068	32
NISSAN	102-6001	.0063	30
	202-6001	.0065	40
	202-6002	.0063	30
	202-6003	.0065	40
	202-6004	.0070	40

ROD BOLT STRETCH & TORQUE SPECS

Make	Rod Bolt Part No.	Stretch (inches)	ARP Lube (ft./lbs.)
NISSAN (cont.)	202-6005	.0066	40
OLDSMOBILE	181-6001	.0060	50
	184-6001	.0062	50
	185-6001	.0067	50
OPEL/VAUXHALL	109-6001	.0053	32
	109-6002	.0054	24
	205-6002	.0062	40
PEUGEOT	117-6101	.0072	35
PONTIAC	190-6001	.0085	50
	190-6002	.0063	50
	190-6003	.0080	75
	190-6004	.0057	61
	191-6001	.0062	40
	194-6001	.0062	40
PORSCHE	204-6001	.0117	45
	204-6002	.0112	50
	204-6003	.0094	45
	204-6004	.0117	45
	204-6005	.0120	35
	104-6006	.0050	40
RENAULT	116-6001	.0049	36
	209-6003	.0059	38
	216-6301	.0065	40
TOYOTA	203-6001	.0057	40
	203-6002	.0063	50
	203-6003	.0055	35
	203-6004	.0065	45
	203-6005	.0074	50

Make	Rod Bolt Part No.	Stretch (inches)	ARP Lube (ft./lbs.)
VOLKSWAGEN	104-6001	.0050	40
	104-6002	.0070	40
	104-6003	.0077	40
	104-6004	.0087	30
	104-6005	.0050	32
	204-6006	.0078	38
GENERAL REPL.	200-6002	.0048	60
	200-6003	.0061	60
	200-6004	.0042	60
	200-6006	.0054	60
	200-6201	.0071	75
	200-6202	.0071	75
	200-6203	.0066	75
	200-6204	.0071	75
	200-6205	.0066	75
	200-6206	.0061	75
	200-6207	.0060	45
	200-6208	.0070	45
	200-6209	.0058	47
	200-6210	.0056	26
	300-6601	.0060	85
	300-6602	.0069	50
	300-6603	.0045	50
	300-6608	.0057	32
	300-6701	.0070	85
	300-6702	.0067	50
	300-6703	.0069	50
	300-6704	.0064	55
	300-6706	.0065	75
	300-6708	.0060	30



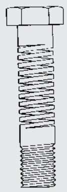
Drag racing's winningest driver, John Force, relies on ARP.

Tony Schumacher puts ARP fasteners to the test in Top Fuel.

PROPER FASTENER RETENTION

There are three methods that can be employed to determine how much tension is exerted on a fastener; using a torque wrench, measuring the amount of stretch, and turning the fastener a pre-determined amount (torque angle). Of these methods, use of a stretch gauge is the most accurate.

It is important to note that in order for a fastener to function properly it must be "stretched" a specific amount. The material's ability to "rebound" like a spring is what provides the clamping force. You should know that different materials react differently to these conditions, and ARP engineers have designed each fastener to operate within specific ranges.



To obtain the correct amount of clamping force a fastener should actually be stretched a measured amount. A properly used fastener works like a spring!

On the other hand, if a fastener is over torqued and becomes stretched too much – you have exceeded the yield strength and it's ruined. If the fastener is longer than manufactured – even if it is only .001," it is in a partially failed condition. Therefore, ARP has engineered its fasteners with the ductility to stretch a given amount and rebound for proper clamping.

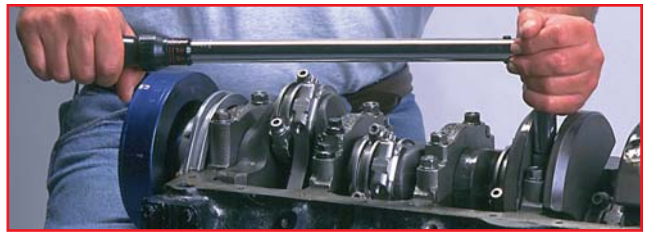
Heat, primarily in aluminum, is another problem area. Because the thermal expansion rate of aluminum is far greater than that of steel it is possible to stretch a fastener beyond yield as the aluminum expands under heat. An effective way of counteracting material expansion is through producing a more flexible bolt.

The Torque Angle Method

Since the amount that a bolt or nut advances per degree of rotation is determined by the thread pitch, it would appear that the amount of stretch in a given bolt or stud can be accurately predicted by measuring the degrees of turn from the point where the underside of the bolt head or nut face contacts the work surface. Termed the "torque angle" method, this procedure has long been the standard of civil engineering. It has been suggested that torque angle is a relatively simple and valid procedure to use in our "blind" installations – where it is not possible to physically measure the actual bolt stretch.

ARP has conducted extensive evaluations of the torque angle method. We have concluded that, for our purposes, it is suitable only when individually calibrated for each installation.

Simple calculation of bolt stretch based on thread pitch is not accurate. No material is incompressible. When a bolt or a stud is preloaded or stretched, the components being clamped compress to some small extent. When we are looking for bolt stretch of only a few thousandths of an inch, the amount of clamped material compression becomes a very real factor. Our investigation has proven that installed stretch is dependent, not only on the pitch of the thread and the degree of rotation, but also on the amount of compression of the clamped components, the length of the male fastener, the amount of engaged thread, the type of lubrication and the number of times that the fastener has been cycled. For example, for the same degree of rotation, the actual amount of bolt stretch will be critically different between an aluminum cylinder head and a cast iron cylinder head – or a steel main cap on an aluminum block and a steel main cap on a cast iron block. Further, there is a significant difference between the long and short cylinder head bolts or studs on the same head. The torque angle method can be accurate – but only if each individual installation has been previously calibrated by direct measurement of bolt stretch. When using the torque angle method, it is best to begin rotation from some small measured torque – no more than ten lb./ft. – rather than the first point of contact with the work face. To achieve accuracy it is also best to cycle the fasteners five times before either calibrating or installing.



Using A Torque Wrench

If the stretch method cannot be used in a particular installation, and the fasteners must be installed by torque alone, there are certain factors that should be taken into account. ARP research has verified the following "rules" pertaining to use of a torque wrench:

1. The friction factor changes from one application to the next. That is, the friction is at its highest value when the fastener is first tightened. Each additional time the fastener is torqued and loosened, this value gets smaller. Eventually the friction levels out and becomes constant for all following repetitions. Therefore, new fasteners should be tightened and loosened through several cycles before applying final torque. The number of times depends on the lubricant. For all situations where ARP lubricants are used, five cycles are required before final torquing.

2. The lubricant used is the main factor in determining friction, and therefore, the torque for a particular installation. Motor oil is a commonly used lubricant because of it's ready availability. If less friction is desired in order to install the fasteners with less torque, special low friction lubricants are available. With special lubes, the required torque can be reduced as much as 20 to 30 percent. It is important to keep in mind that the reverse is also true. If the torque value has been specified for a particular fastener on the basis of low friction lube, installing the fastener with motor oil will result in insufficient preload; the torque has to be increased to compensate for the extra friction caused by the motor oil.

3. Surface finish is also important. For example, black oxide behaves differently than a polished fastener. It is therefore important to observe the torque recommendations supplied with each fastener.

NOTE: It is possible for even the most expensive of torque wrenches to lose accuracy. We have seen fluctuations of as much as ten (10) foot pounds of torque from wrench to wrench. Please have your torque wrench checked periodically for accuracy.

The Stretch Gauge

We highly recommend using a stretch gauge when installing rod bolts and other fasteners where it is possible to measure the length of the fastener. It is the most accurate way to determine the correct pre-load in the rod bolt. Simply follow manufacturer's instructions, or use the *chart on page 25 of this catalog* for ARP fasteners. Measure the fastener prior to starting, and monitor overall length during installation. When the bolt has stretched the specified amount, the correct preload, or clamping load, has been applied. We recommend you maintain a chart of all rod bolts, and copy down the length of the fastener prior to and after installation. If there is a permanent increase of .001″ in length, or if there is deformation, the bolt should be replaced. *A sample stretch monitoring chart is on page 28.*

see page 88 for complete information on stretch gauges

THE IMPORTANCE OF PROPER ROD BOLT STRETCH/TORQUE...

Whether measured by stretch or by torque, properly preloading a rod bolt is essential for trouble-free performance. If a bolt is installed without sufficient preload (or pre-stretch), every revolution of the crankshaft will cause a separation between the connecting rod and rod cap. This imposes additional stretch in the bolt. The stretch disappears when the load is removed on each revolution, or cycle. Over time, this cycle stretching and relaxing can cause the bolt to fail due to fatigue, just like a paper clip that is bent back and forth by hand. To prevent this condition, the bolt's pre-load must be greater than the load caused by engine operation.

A properly installed bolt remains stretched by its preload and isn't exercised by the cyclic loads imposed on the connecting rod. A quality bolt will stay stretched this way for years without failing. The important thing is to prevent the bolt from failing due to fatigue by tightening it to a load greater than the demand of the engine. Protect your boltsčtighten them as recommended.

You can easily monitor the condition of the rod bolts through use of a stretch gauge, or a micrometer for that matter. Prior to installing the rod, measure the length of the bolt in a "relaxed" (untorqued) state. Write this down. You can make up a chart similar to the one shown on this page to properly keep track of the data. When you tear the engine down for maintenance, again measure the length of each rod bolt – being careful to keep everything in the proper order. If any of the rod bolts have taken a permanent set and have stretched by .001″ or longer you should replace the fastener **IMMEDIATELY!** The stretching is a sure indicator that the bolt has been compromised and taken past its yield point.

In other types of bolted joints, this careful attention to tightening is not as important. For example, flywheel bolts need only be tightened enough to prevent them from working loose. Flywheel loads are carried either by shear pins or by side loads in the bolts; they don't cause cyclic tension loads in the bolts. Connecting rod bolts, on the other hand, support the primary tension loads caused by engine operation and must be protected from cyclic stretching. That's why proper tightening of connecting rod bolts is so important. *See page 25 for recommended stretch and torque.*

Friction is an extremely challenging problem because it is so variable and difficult to control. The best way to avoid the pitfalls of friction is by using the stretch method. This way preload is controlled and independent of friction. Each time the bolt is torqued and loosened, the friction factor gets smaller. Eventually the friction levels out and becomes constant for all following repetitions. Therefore, when installing a new bolt where the stretch method can not be used, the bolt should be tightened and loosened several times before final torque. The number of cycles depends on the lubricant. For ARP recommended lubes, five loosening and tightening cycles is sufficient.

A rod bolt stretch gauge is one of the most important tools a serious engine builder can own. It's valuable in properly setting up a rod for resizing, obtaining the proper torque load when installed in the engine, and monitoring the condition of the bolt while in use.

ROD BOLT STRETCH MONITORING CHART

ROD #1	ROD #2	ROD #3	ROD #4
INSIDE BOLT	*INSIDE BOLT*	*INSIDE BOLT*	*INSIDE BOLT*
IN______OUT_____	IN______OUT_____	IN______OUT_____	IN______OUT_____
OUTSIDE BOLT	*OUTSIDE BOLT*	*OUTSIDE BOLT*	*OUTSIDE BOLT*
IN______OUT_____	IN______OUT_____	IN______OUT_____	IN______OUT_____
ROD #5	**ROD #6**	**ROD #7**	**ROD #8**
INSIDE BOLT	*INSIDE BOLT*	*INSIDE BOLT*	*INSIDE BOLT*
IN______OUT_____	IN______OUT_____	IN______OUT_____	IN______OUT_____
OUTSIDE BOLT	*OUTSIDE BOLT*	*OUTSIDE BOLT*	*OUTSIDE BOLT*
IN______OUT_____	IN______OUT_____	IN______OUT_____	IN______OUT_____