CRIMP TOOLING – WHERE FORM MEETS FUNCTION

The cost of quality can be expensive

Introduction

Quality, cost, and throughput are associated with specific measurements and linked to process variables. Crimp height, pull test values, leads per hour, and crimp symmetry are some of the measures used to monitor production termination processes.

Many variables affect the process such as wire and terminal quality, machine repeatability, setup parameters, and operator skill.

Crimp tooling is a significant contributor to the overall crimp termination process. The condition of crimp tooling is constantly monitored in production by various means. These means are often indirect measures. Crimp Quality Monitors and crimp cross sections are methodologies that infer the condition of the crimp tooling. Visual inspection of the crimp tooling can be used to check for gross failures such as tool breakage or tooling deformation which occurred as a result of a machine crash. Continuous monitoring of production will help determine when the process needs to be adjusted and the replacement of crimp tooling can be one of the adjustments that is made.

Key Crimp Tooling Characteristics

There are four major categories of key characteristics for crimp tooling. These are:

- **Geometry and associated tolerances**
- **Materials**
- **Surface condition**
- **Surface treatment**

Each of these categories contributes to the overall performance of the production termination process.

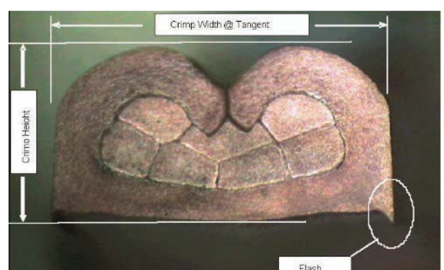
Crimp tooling can a have positive effect on the quality, cost, and throughput of the termination process. High quality crimp tooling can produce high quality crimps with less in-process variation over a greater number of terminations.

It is difficult to distinguish critical tooling attributes with visual inspection only. Some attributes cannot be inspected even by running crimp samples. This paper will present the reader with information that identifies key crimp tooling attributes and the effect of those attributes on the crimping process.

Geometry and Associated Tolerances

Terminals are designed to perform to specification only when the final crimp form is within a narrow range of dimensions. Controlling critical crimp dimensions is influenced by many factors including:

- Wire size and material variation
- Terminal size and material variation
- Equipment condition



Cross Section Defining Crimp Width, Crimp Height and Flash

The final quality and consistency of a crimp can never be any better than the quality and consistency of the tooling that is used. If other variations could be eliminated, tooling can and should be able to produce crimp forms that are well within specified tolerances. In addition, variation from one tooling set to another should be held to a minimum. Crimp tooling features that are well controlled and exhibit excellent consistency from tooling set to tooling set can result in shorter setup time as well as more consistent production results.

Some critical crimp characteristics are directly defined by the tooling form and are obvious. These include crimp width & crimp length.

Other critical crimp characteristics can be related to several tooling form features and/or other system factors. These may be less obvious and include:

- Flash
- Roll, twist, and side-to-side bend
- Up/down bend
- Crimp symmetry
- Bellmouth

The following discussion focuses on two characteristics, crimp width and flash, as examples of how tooling affect crimp form. Similar arguments can be applied to the others.

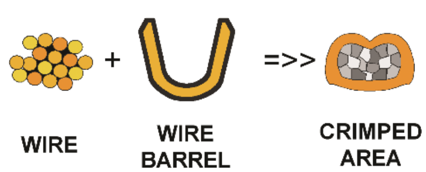
Crimp Width

Crimp width is a good example of a feature that should be consistent and in control between different crimpers of the same part number. The reason for this is quite straightforward. For a given terminal and wire combination, it is necessary to achieve an area index, AI, which is determined by the terminal designer for optimal mechanical and electrical performance. Crimp height, CH, and crimp width, CW, directly affect achieving proper AI. Area index, AI (as a percentage), is defined as:

$$AI = \frac{A_t}{A_W + A_B} \times 100$$

where A_t is the total area of the wire and barrel after crimping. A_W and A_B are, respectively, the initial cross-sectional areas of the wire and barrel before crimping.

Area Index

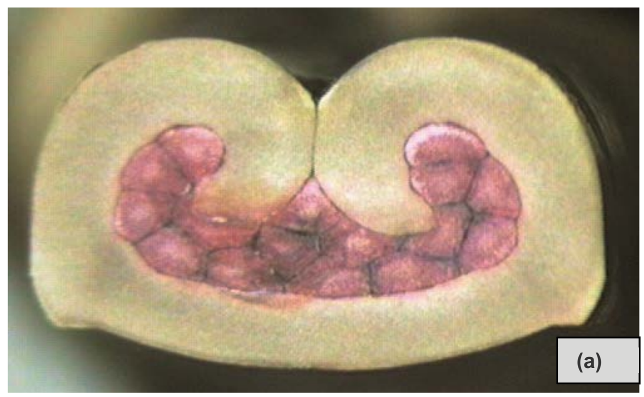


TOTAL UNCRIMPED AREA = WIRE + BARREL

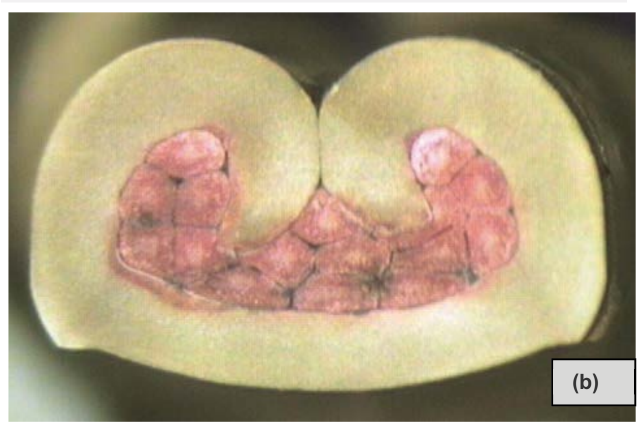
% Area Index =
(Total Crimped Area / Total Un-Crimped Area)

A typical design point for AI is 80%. In order to maintain the same AI, the crimp height, CH, needs to change inversely to the change of crimp width, CW, in approximately the same proportion. Thus, if the CW increases +2%, the CH needs to change approximately -2% in order to achieve the same AI design point. At first glance that may not seem significant, but in reality it can be very significant. Using another general industry design rule of the ratio of CH to CW of approximately 65%, a typical set of dimensions used as an example may be: CW = 0.110 in, CH = 0.068 in

Therefore, varying the CW by 2% would result in a CH variation of 2%, or 0.0014 in. At a CH tolerance of ± 0.002 in, 35% of the total CH tolerance would be used by a 2% variation in CW. Thus, the importance of crimp width control is obvious when tooling is changed during a production run.



Cross Sections Showing Minimum (a) and Maximum (b) Area Index per Terminal Specification—a Variation of ± 3.5%

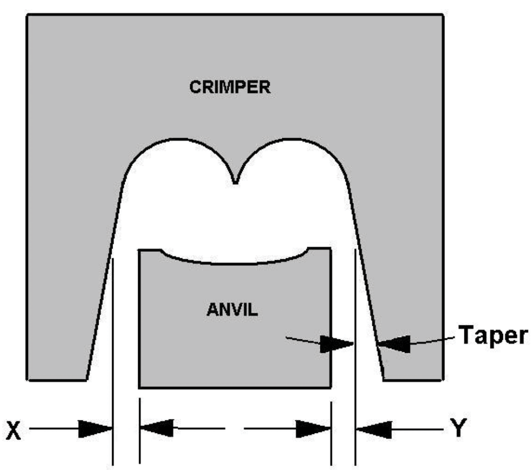


Flash

Most crimp terminations have a requirement to limit flash. Flash is defined as the material which protrudes to the sides of the terminal down and along the anvil. Flash is normal in the crimping process but excessive flash is very undesirable. Controlling flash requires a balance of several geometric factors. Other factors influencing flash are related to surface finish and friction, which will be discussed later in this paper.

A dominant factor in controlling flash is controlling the clearance between the crimper and anvil during the crimp process. Defining the ideal clearance could in itself be a simple matter were it not for two facts:

- In order to minimize terminals' sticking in the crimper, the sides of the crimper are tapered. Thus the clearance between the anvil and crimper varies throughout the stroke.
- Crimper and anvil sets are typically designed to terminate two to four wire sizes. This creates multiple crimp heights. Since the sides of the crimper are tapered to minimize terminal sticking, the maximum clearance permitted without creating flash must be assigned to the maximum crimp height specified for the tooling set. In addition, a minimal clearance must be maintained for the smallest crimp height specified by the tooling set to prohibit contact between the anvil and crimper.



Crimper to anvil clearance is thus a combination of crimp width, crimper leg taper, anvil width, and crimp height. The critical design point is at the largest crimp height. This contribution to the gap is directly dependent on dimensional control.

The following is offered as an example:

Nominal condition: CH = 0.073 in, CW = 0.110 in

Crimper leg taper = 3.0 degree

Anvil Width = 0.109 in

Nominal anvil to crimper total clearance = 0.005 in

The clearance can grow rapidly with small changes to the nominal dimensions:

CH remains unchanged = 0.073 in

Increase in crimp width, CW, = 0.0008 in

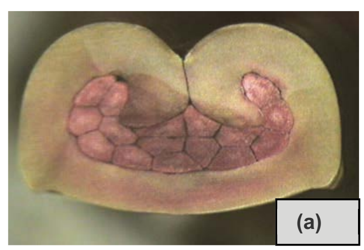
Increase in crimper leg taper = 0.8 degree

Decrease in anvil width = 0.0008 in

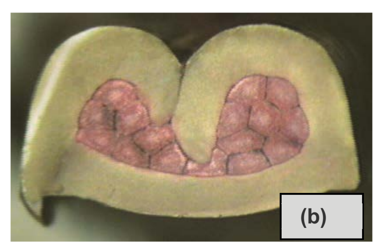
The increase in total clearance is this case = 0.0026 in

This is more than a 50% increase in the nominal design clearance, which can result in unacceptable flash

Dimensional control is clearly critical.



Significant flash can be generated with excessive anvil to crimper clearance, as shown by nominal design condition (a) and +0.003 in over nominal



Materials

The material selection for tooling is critical. The material must be able to meet the in-service demands placed on the tooling components. The two critical tooling components to be reviewed are the wire crimper and the anvil.

The wire crimper and the anvil have different functional demands. Both have the need to withstand high loads and moderate shock. However, the wire crimper is in fact an aggressive forming tool. It must withstand high shear loading that is a result of frictional loads generated as the terminal barrel slides along the crimper surfaces in the forming process, and then as the terminal barrel is plastically deformed and extruded to complete the termination. The anvil experiences some of the same conditions but to a much lower level of severity.

The wire crimper and the anvil can be likened to a punch and die in the world of metalworking. The materials used in punch and die applications have been well documented, along with the material selection process. The added severity of the aggressive forming and the terminal and wire extrusion during crimping add complexity to the material selection. The material selection process involves:

- Strength of materials with emphasis on toughness needed to withstand the moderate shocks generated during crimping
- Wear resistance to maintain form

In addition to the above design considerations, there exists another phenomenon that occurs during crimping that can significantly shorten the useable life of a wire crimper. Material can be transferred from the terminal barrel to the wire crimper. This material buildup can result in unacceptable terminations. The crimped terminal surfaces can actually be deformed by the indentations of the deposited material. Crimp deformation may result due to increased friction. Tooling wear can be accelerated due to higher crimp forces. Surface treatments that minimize this material transfer are critical to extended tooling life.

Strength of Materials

Crimpers and anvils are designed to be able to withstand stresses that are typically encountered during crimping. The basic design of tooling with reference to size and geometry has been well analyzed and generally stresses generated during crimping are able to be accommodated. However, there are always demanding applications that will tax the design to its stress limits. In those cases, geometry and material may depart from the standard design. These exceptions are dealt with on a one-by-one basis and will not be discussed here.

It is the unique requirement of stress and shock that needs to be discussed. Peak crimp loads go from zero to maximum in less than 40 ms. Tooling needs to withstand this load cycle at a rate of greater than once per second. Several classes of tool steels are suitable and are well described in the material handbooks. It is the processing of these materials that can make a significant performance difference.

In order to withstand the rapid loading to a high stress on a repeated basis, the surface of the material must minimize cracks and imperfections that may be generated during the machining and/or heat treat operations. It is important that grain structure be controlled in size and orientation to achieve maximum and consistent service life. Decarburization of the surface during heat treating must be controlled. Heat treating process controls are critical to reproducing the optimal surface. Machining processes must also be controlled to avoid surface cracking due to excessive heat generation during overly aggressive material removal. Likewise, localized tempering may occur, which can soften material beyond the effective range.

These variations in final material and surface conditions are not readily detectable with a visual inspection. They can manifest themselves during service and result in unacceptable tooling performance.

Wear Resistance

Wear is generally described as the gradual deterioration of a surface through use. Several types of wear exist and include adhesive, abrasive, and pitting. By design, the tooling is able to withstand normal surface loads. Thus, pitting is typically not an issue.

The primary wear mode experienced by crimp tooling is adhesive wear. Adhesive wear occurs as two surfaces slide across each other. Under load, adhesion, sometimes referred to as cold welding, can occur. Wear takes place at the localized points of adhesion due to shear and deformation. Adhesion is highest at the peaks of surface finish because that is where the load is greatest. During crimping, the ideal conditions exist for adhesive wear. That is,

- High loading due to crimp force
- Sliding surfaces due to crimp formation, and terminal and wire extrusion

Wear will generally manifest itself more significantly at edges of a surface. However, adhesive wear is often observed over substantial areas of the tooling. It is important to note here that the wire crimper is the component most susceptible to adhesive wear. Generally, adhesive wear will be directly related to load and to the amount of relative movement between the two materials. Although the anvil may have equal loading, the amount of relative movement between the terminal and tooling is many times more at the crimper than at the anvil. The insulation crimper typically experiences lower adhesive wear because the load is reduced compared to the wire crimp and the relative movement is less than that of the wire crimper, since there is no terminal and wire extrusion at the insulation crimp.

Adhesive wear can be controlled in the selection of the material. Different alloys exhibit better or worse wear properties. These properties can be measured and are well documented. Adhesive wear is inversely proportional to the hardness of the material. Thus, the harder the material, the less adhesive wear. In crimp tooling, there is often a tradeoff that is made. In order to achieve higher wear resistance, the material often exhibits lower toughness by composition, hardness, or both. The final material selection is often based on years of experience. One material may have high wear characteristics and lower toughness, and be suitable for a small terminal since the margin of safety on stress is high. Another terminal may be large and the toughness could be of more importance due a lower stress design margin. The ability to design and manufacture crimpers from several materials will enable optimal material selection for a specific application.

The final property that affects adhesive wear is surface finish. As stated earlier, adhesion is highest at the peaks of the surface. Thus, the smoother the finish, the less significant the peaks and the less significant the adhesion. Adhesive wear can be reduced with a lower surface finish. Surface finish affects other crimping performance parameters. These are discussed in the next section.

Abrasion can occur depending on terminal surfaces. If a terminal is plated with an abrasive substance, the tooling could suffer from abrasive wear. This would be an atypical condition and would be handled by special design.

Other applications where abrasive wear is the primary wear mode involve terminals made of steel and stainless steel. Extensive testing has shown chromium plating is the best surface treatment that can be used on crimpers designed for these abrasive terminals. However, in these applications, crimpers will not last as long as those crimpers used to crimp terminals made of other, less abrasive base materials. Using a lubricant (in those applications where this is acceptable) has shown to increase the life of the crimper. However, even when lubricated the crimper life can be expected to be shorter when crimping steel or stainless steel terminals.

Once abrasive wear has taken place to the point where the chromium plating has been removed from the base tool steel of the crimper, as successive crimp cycles occur, further wear will happen very quickly. Without the protective chromium plating, the underlying surface will then be subject to either further abrasive wear, or adhesive wear. For this reason, care should be taken to replace the crimper as soon as wear is visible on the surface of the crimper.

Surface Condition

Surface condition can affect the performance of the crimp tooling as well as the longevity of service. As noted in the previous section, a hard, smooth surface has improved adhesive wear properties and, thus, longer service life. The other attribute that needs to be considered is friction.

Friction is a contributing factor in determining the final crimp form and process characteristics. Low tooling friction results in lower crimping force and thus can influence crimp form as well as tooling life. Consistent frictional characteristics between tooling sets will result in reduced process variation.

Friction of the crimp tooling surfaces is influenced by factors similar to those that influence adhesive wear—hardness and surface finish. Generally, harder materials exhibit lower coefficients for sliding friction. Friction coefficients have also been shown to be related to surface finish. Manufacturing processes need to produce consistent results such that when tooling sets need to be changed in production, minimum disruption in crimp quality is achieved. It has been found that maintaining surface hardness above Rc 55 as well as keeping surface finishes to 8 micro-inches or less is desirable to obtain consistent crimp results and minimize adhesive wear.

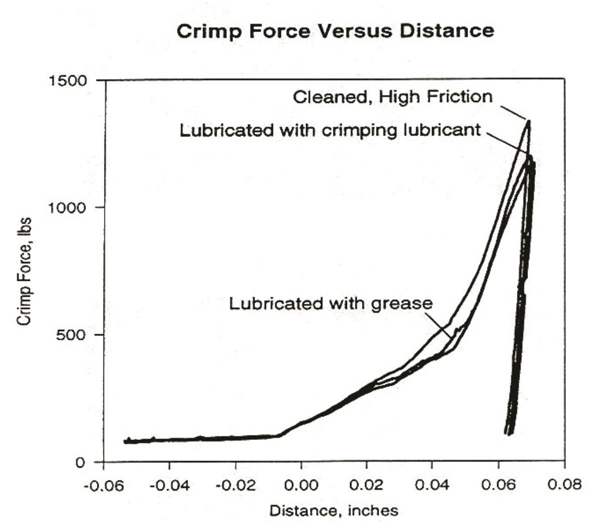


Figure 16 Crimping forces versus distance.

Typical Effect of Friction on Crimp Force

Surface Treatment

Surface condition can affect the performance of the crimp tooling as well as the longevity of service. A hard, smooth surface has improved adhesive wear properties and, thus, longer service life. The other attribute that needs to be considered is friction.

A commonly accepted approach to improved crimp tooling performance and life has been to apply a surface treatment to the crimp area. The wire crimper has been defined in previous discussions as tooling component that is subjected to the severest duty cycle. Thus, applying an appropriate surface treatment to the wire crimper will have the most benefit to crimp performance and tooling life. These treatments can include hard metal plating or ceramic coating.

An example of a treatment that has been successful in achieving significant level of performance and life improvements is hard chromium plating.

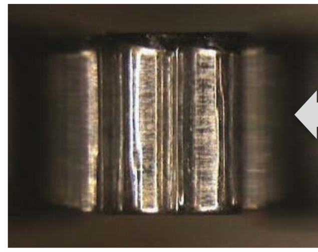
Chromium plating has a very low coefficient of friction. As noted, friction has a significant effect on crimp form. The static and sliding coefficients of friction for steel on steel are typically 0.30 and 0.20 respectively. Chromium plated steel on steel can reduce the static and sliding coefficients to 0.17 and 0.16.

Chromium plating also reduces wear resistance. Adhesive wear resistance is improved as surface hardness improves. Chromium plating typically exhibits a hardness Rc 65+. This hardness level greatly enhances resistance to adhesive wear. This now frees up the designer to consider more base metal options. A base material of reduced wear resistance but greater toughness can be selected and its wear resistance improved with chromium plating. Thus, chromium plating can enable a better tooling solution for the crimp production process.

Perhaps one of the most significant effects of chromium plating, is its resistance to adhesion and cold welding. A side effect of adhesive wear is the transfer of material from the terminal to the wire crimper. By definition, adhesive wear is caused by material adhering to localized points on the surface. Some of the adhesion results in the surface material being worn away and some in the transfer of material from the terminal to the crimper. As more cycles occur, more material is transferred. Thus there a resultant buildup of terminal material on the crimper.

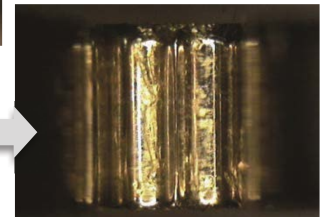
This buildup will result in two potentially catastrophic failures:

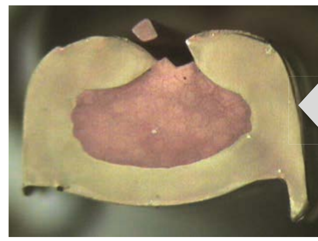
- The built-up material will create deformations in the terminal surface, resulting in unacceptable crimps.
- Crimps will be greatly distorted due to significant changes in the friction factor and result in terminals not conforming to the desired form. Unacceptable crimp forms, such as unsymmetrical cross-section, excessive flash, and open barrels can result.



Chromium plated crimper surface after 100,000 terminations. Note there is no visible buildup of material.

Unplated crimper surface after 60,000 terminations. Note significant buildup of material.





Gross deformation of crimped terminal resulting from material buildup in crimper.

Visible deformation of outer crimp surface because of indentation from material buildup on crimper.

Chromium plating has the ability to be applied uniformly and consistently and exhibits excellent adhesion to the base metals. The unique benefits of chromium plating, such as ease of application, consistency of plating, adhesion to base metal, extremely low coefficient of friction, very high hardness, and resistance to adhesion, make it truly difficult to match in crimp performance and durability. However many alternative coatings are being attempted, and some show excellent promise in specific applications.

Summary

This paper has explored four categories of characteristics that are key to high performance tooling. Several examples have been discussed which demonstrate how minor variations in those characteristics can have measurable and sometimes significant effects on the resultant crimp form and its compliance to specifications. These same characteristics can affect tooling service life. It is also a logical extension of these discussions to conclude that variations of these characteristics from one tooling set to another tooling set can affect process control when tooling changes are required in production. Maintaining process control may require additional setup time. Quality tooling that addresses the key characteristics of geometry, materials, surface condition, and surface treatment is an important component of your total quality control program.

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