

GALLING RESISTANCE OF ALLOY 25

by
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Over time, the exceptional galling resistance of Brush Alloy 25 has become common knowledge among equipment designers. Galling resistance has been one of the primary reasons that Alloy 25 has been selected for equipment where the service conditions included high strength and relative motion between metal components. Alloy 25 has been shown to resist galling to many other metals and to resist galling to other Alloy 25 parts. The data in this article have been obtained to better quantify the galling resistance of Alloy 25. This information provides engineers with a better estimate of the design stress that can be applied when using Alloy 25.

Galling has been defined in a variety of ways. An appropriate way to describe **galling is the condition where metals begin to cold weld or bond to one another under the joint influences of compressive stress and relative motion at temperatures far below the melting temperature.** As the galling condition develops, the two parts adhere to one another and become bonded. When this occurs the parts seize and motion stops.

Galling occurs in many metals under stress and is usually more severe when components are made from the same material. Galling is usually alleviated through lubrication. However, there are service conditions where lubrication is not possible or where the lubricant film cannot be maintained. Under these conditions, designs often employ materials with different metallurgical structures or different hardness to reduce galling. The material choice is often based on experience rather than engineering data.

Among common engineering materials, **galling is a particular problem for nickel alloys and stainless steels.** For many applications, corrosion resistance of these metals is the principal reason for their selection, however, the stress required to initiate galling in these metals is generally low. Galling is one of the primary reasons for equipment failure and increases maintenance costs in many industries.

GALLING TEST METHOD

In response to galling problems, a galling test method, Figure 1, was developed by Armco and adopted by the stainless steel industry to measure the stress at which galling occurs. This test method has been incorporated into the **ASTM G-98** specification and testing procedure. The testing method can be applied to any combination of metals and can be conducted in most testing laboratories.

The testing procedure employs a stationary block of one metal and a cylindrical button of the same or another metal. The button is placed on the block, loaded in compression and rotated 360 degrees to provide relative motion. The surfaces of the button and the block are not lubricated. The surface finish of both the block and the button are standardized to eliminate surface finish as a testing variable.

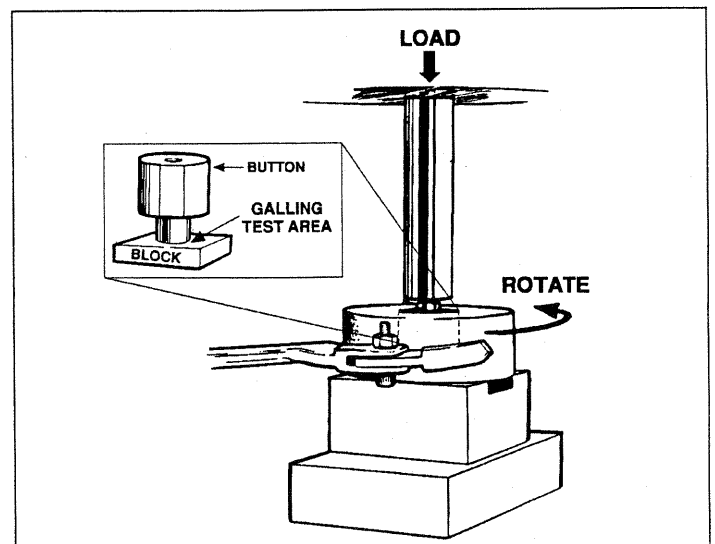


Figure 1

The surface of the block and button are visually examined to detect galling. If galling has not occurred, the test is repeated at a higher stress until galling does occur or until the yield strength of either the block or the button material has been exceeded. The result of the test procedure is called the **Threshold Galling Stress**. Some combinations of materials may not exhibit a Threshold Galling Stress within the elastic stress region. For these materials, the lower yield strength of the two materials has been used to define a Threshold Galling Stress for the combination. This value was selected because the yield strength is considered the maximum strength used in designing mechanical components. The data has been rounded to the nearest 5,000 psi for most materials. For Threshold Galling Stresses less than 5,000 psi, data have been rounded to the nearest 100 psi. The convention of adding a "+" after the Threshold Galling Stress indicated that galling did not occur and the lower yield strength method was used.

This testing method has been applied to Alloy 25 and a number of other metals to provide useful information for Brush customers and design engineers in a number of industries considering Alloy 25 in their designs. In these tests, the Alloy 25 AT tested was manufactured to AMS 4533. Alloy 25 produced to this specification is used for aerospace bearing applications where galling is important. Testing at stresses in excess of 100,000 psi were not conducted because of difficulties in using the test equipment and concerns for operator safety at these high stress levels.

Galling data for a number of stainless steels have been available in the literature, but similar data have not been available for nickel based alloys and for light metals. As the galling characteristics for combinations of Alloy 25 and these metals were measured, the self galling characteristics of a number of engineering alloys was determined. Metals other than Alloy 25 were obtained from service centers or the producers of the alloys and were tested in the condition that they were received.

GALLING TEST RESULTS

The results of the galling test program are described in the following tables:

| Table | Description |
|---------|------------------------------------------------------------|
| 1 | Alloy 25 Self-galling Characteristics |
| 2 | Galling Characteristics of Alloy 25 and Stainless Steels |
| 3 | Alloy 25 and Light Metals |
| 4 | Light Metal Self-galling Characteristics |
| 5 | Galling Characteristics of Alloy 25 and Non-ferrous Alloys |
| 6 | Non-ferrous Metal Self-galling Characteristics |
| 7 | Galling Characteristics of Alloy 25 and Steels |
| 8 and 9 | Stainless Steel Galling Characteristics |

SELF-GALLING CHARACTERISTICS OF ALLOY 25

The data in Table 1 shows that **the self-galling resistance of Alloy 25 is superior to many other metals**. Galling did not occur for any of the three Alloy 25 tempers tested to the maximum 100,000 psi compressive stress. The annealed (A) and cold worked (H) tempers were not tested because Alloy 25 is not frequently used in this temper. The A and H tempers are not presumed to be galling resistant.

GALLING CHARACTERISTICS OF ALLOY 25 AND STAINLESS STEELS

The data in Table 2 describe the galling characteristics of Alloy 25 (AT) with a number of stainless steel alloys. The test program did not produce galling in any of the Alloy 25 - stainless steel combinations. The values of the Threshold Galling Stress column are related to the yield strength of the stainless steels and to the number of samples available for testing. Tests were conducted for a number of Alloy 25 - stainless steel combinations at stresses in excess of the stainless steel's yield strength. Although the tests did not show galling, the stainless steel samples deformed. **The implication of the data in Table 2 are that Alloy 25 can be used without galling at stresses up to the stainless steel's yield strength.**

The data in Table 2 can be compared with the galling characteristics of a number of stainless steels in "*Review of the Wear and Galling Characteristics of Stainless Steels*" published by the AISI in 1978. Some of the information from this handbook are shown in Tables 8 and 9. These data show that stainless steels generally have low galling resistance, combinations of certain stainless steels have better galling resistance and Waukesha 88 and Armco Nitronic 60 have the best galling resistance.

GALLING CHARACTERISTICS OF ALLOY 25 AND LIGHT METALS

The data in Table 3 describe the galling characteristics of Alloy 25 and aluminum and titanium alloys. The data show that **Alloy 25 will gall when in contact with light metal alloys**. Galling occurs at stresses much lower than the yield strength of the light metals and the nature of the galling to be dependent on the light metal alloy. Where possible lubricants should be used to reduce contact between the metals. For equipment made from Alloy 25 and light metals such as Al 1100 or Ti -Al-4V, galling could produce a coating of Alloy 25 on the light metal surface after a "break in" period. The coating would result in an Alloy 25 - Alloy 25 couple and galling would cease. The galling behavior of Titanium CP and Alloy 25 resulted in samples where both of the metals had transferred to the other. This metal pair has poor galling characteristics.

The self-galling characteristics of light metals are described in Table 4. **The data show that light metals are extremely prone to galling.** The traditional approach to solving galling in light metals is with lubricants. The galling characteristics of

Alloy 25 and light metals could be used to design equipment to resist galling as shown in Figure 2. Each of the two washers in the figure can gall to the light metal component producing a Alloy 25 - Alloy 25 interface which resists galling. This alternative approach results in a galling resistant interface that does not require lubrication.

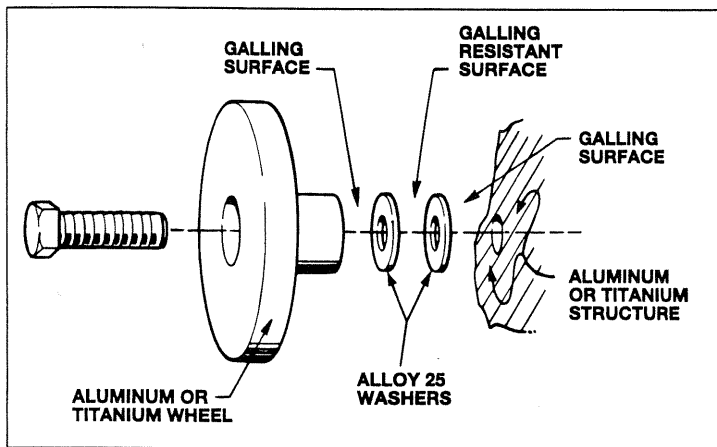


Figure 2

GALLING CHARACTERISTICS OF ALLOY 25 AND NON-FERROUS ALLOYS

The data in Table 5 describe the galling characteristics of Alloy 25 and non-ferrous engineering alloys. **The galling characteristics of Alloy 25 and nickel based alloys vary among the alloys tested.** No trend emerged among the Threshold Galling Stress data for these alloys. The galling characteristics must be examined for each metal pair. Alloy 25 galled to the non-ferrous alloys in most of the test data. The galling situation may decrease after a "break in" period when a coating of Alloy 25 has formed on a number of the non-ferrous alloy. Where possible lubricants should be used to reduce contact between the metals. The galling behavior of nickel and Alloy 25 resulted in samples where both of the metals had transferred to the other. This metal pair has poor galling characteristics.

The data in Table 6 describe the self-galling characteristics of a number of non-ferrous alloys. These data show that there is little resistance to galling among these non-

ferrous alloys. Data for the higher strength non-ferrous alloys and Alloy 25 show considerable improvement when compared with the self-galling data for these alloys. **Using Alloy 25 components with Inconel 600, Monel K-500 and MP35N can result in higher Threshold Galling Stress for the resulting design.**

GALLING CHARACTERISTICS OF ALLOY 25 AND STEELS

The data in Table 7 describe the galling characteristics of Alloy 25 and steels. **The galling resistance of Alloy 25 and the higher alloyed steels was superior to that of Alloy 25 and the lower alloyed steels.** When galling occurred, Alloy 25 was transferred to the steels. The galling situation may decrease after a "break in" period when a coating of Alloy 25 has formed on a number of the steels. This has been observed in fabricated components that perform better in sliding after a "break in" period.

CONCLUSION

The data in this article can be compared directly and used to determine the galling tendency of a number of metal pairs. The galling characteristics depend upon the specific metals in the pair. Galling is not an exact science and the mechanisms that govern galling are not well understood. **Engineering designs should be guided by the empirical data for the specific metals in the design rather than generalized trends about families of alloys.**

The data show that Alloy 25 can be used to reduce or eliminate galling in a number of important engineering alloys. Among the that can benefit from the use of Alloy 25 to reduce galling are: stainless steels, Inconel 600, Monel K-500, MP35N, 8620 and 300M.

When all of the data are compared, Alloy 25 has the best self-galling resistance.

The conclusion reached from this information is that Alloy 25 has superior galling resistance. When combined with high strength, exceptional machinability and its many other qualities, Brush Alloy 25 is the superior material of choice in component designs.

Table 1: Alloy 25 Self-galling Characteristics

| METALS IN CONTACT | | THRESHOLD GALLING STRESS (ksi) |
|----------------------------------------------------------------------------------------------------|----------------------------------|--------------------------------|
| Alloy 25 Temper | 0.2% Offset Yield Strength (ksi) | |
| AT vs. AT | 140 | 100 + |
| HT vs. HT | 150 | 100 + |
| DST vs. DST | 110 | 100 + |
| AT annealed and aged HT cold worked and aged DST annealed and aged to 100-110 yield strength | | + no galling |

Table 2: Galling Resistance of Alloy 25 vs. Stainless

| METALS IN CONTACT | | THRESHOLD GALLING STRESS (ksi) | |
|-----------------------------------------------------------------------------------------------------------|----------------------------------|--------------------------------|------|
| | 0.2% Offset Yield Strength (ksi) | | |
| Alloy 25 145 ksi yield strength | 303 | 45 | 40 + |
| | 304 | 55 | 30 + |
| | 316 | 44 | 30 + |
| | 416 | 92 | 70 + |
| | 440C | 79 | 50 + |
| | Nitronic 50 | 79 | 60 + |
| | Nitronic 60 | 56 | 55 + |
| | Alloy 2205 | 87 | 80 + |
| | Carpenter 20Cb-3 | 72 | 40 + |
| | 15-5 PH | 149 | 90 + |
| | 17-4 PH | 146 | 90 + |
| | Custom 455 | 132 | 60 + |
| Gall Tough | 65 | 50 + | |
| ¹ Alloy 25 galled to steel alloy ² Steel alloy galled to Alloy 25 + no galling | | | |

Table 3: Galling Resistance of Alloy 25 vs. Light Metals

| METALS IN CONTACT | | THRESHOLD GALLING STRESS (ksi) | |
|-----------------------------------------------------------------------------------------|----------------------------------|--------------------------------|-----------------------|
| | 0.2% Offset Yield Strength (ksi) | | |
| Alloy 25 145 ksi yield strength | Al 1100 | 23 | 7.5 ⁽¹⁾ |
| | Al 6061T6 | 53 | <2.5 ⁽²⁾ |
| | Al 7075T6 | 77 | <2.5 ⁽²⁾ |
| | Titanium CP Grade 2 Annealed | 53 | <2.5 ^(1,2) |
| | Ti-6Al-4V | 142 | 7.5 ⁽¹⁾ |
| ¹ Alloy 25 galled to light metal ² Light metal galled to Alloy 25 | | | |

Table 4: Self-galling Resistance of Light Metals

| METALS IN CONTACT | | THRESHOLD GALLING STRESS (ksi) | |
|---------------------------------|-------------------------------------|----------------------------------|------|
| | | 0.2% Offset Yield Strength (ksi) | |
| Al 1100 | vs. Al 1100 | 23 | <2.5 |
| AL 6061T6 | vs. Al 6061T6 | 53 | <2.5 |
| AL 7075T6 | vs. Al 7075T6 | 77 | <2.5 |
| Titanium CP Grade 2 Annealed | vs. Titanium CP Grade 2 Annealed | 53 | <2.5 |
| Ti-6Al-4V | vs. Ti-6Al-4V | 142 | <2.5 |

Table 5: Galling Resistance of Alloy 25 vs. Non-ferrous Alloys

| METALS IN CONTACT | | THRESHOLD GALLING STRESS (ksi) | | |
|---------------------------------------------------------------------------------------------------------------------|---|----------------------------------|-----|----------------------|
| | | 0.2% Offset Yield Strength (ksi) | | |
| Alloy 25 145 ksi yield strength | { | Inconel 600 | 106 | 30 ⁽¹⁾ |
| | | Inconel 625 | 85 | 5 ⁽¹⁾ |
| | | Inconel 718 | 83 | <3.7 ⁽¹⁾ |
| | | Monel 400 | 82 | <30 ⁽¹⁾ |
| | | Monel K500 | 115 | 50 + |
| | | Nickel 200 | 69 | 2.5 ^(1,2) |
| | | Waspaloy | 85 | <2.5 ⁽¹⁾ |
| | | MP35N | 145 | 75 + |
| ¹ Alloy 25 galled to non-ferrous alloy ² Non-ferrous alloy galled to Alloy 25 + no galling | | | | |

Table 6: Self-galling Resistance of Non-ferrous Alloys

| METALS IN CONTACT | | THRESHOLD GALLING STRESS (ksi) | |
|-------------------|------------------|----------------------------------|-------|
| | | 0.2% Offset Yield Strength (ksi) | |
| Inconel 600 | vs. Inconel 600 | 160 | <2.5 |
| Inconel 625 | vs. Inconel 625 | 85 | <2.5 |
| Inconel 718 | vs. Inconel 718 | 83 | <2.5 |
| Monel 400 | vs. Monel 400 | 82 | <2.5 |
| Monel K500 | vs. Monel K500 | 115 | <10.0 |
| Nickel 200 | vs. Nickel 200 | 69 | <0.3 |
| Waspaloy | vs. Waspaloy | 85 | <2.5 |
| MP35N | vs. MP35N (aged) | 280 | 10 |

Table 7: Galling Resistance of Alloy 25 vs. Steels

| METALS IN CONTACT | | THRESHOLD GALLING STRESS (ksi) | | |
|---------------------------------------|---|---------------------------------------------------------------------------------------------------------|-----|--------------------|
| | | 0.2% Offset Yield Strength (ksi) | | |
| Alloy 25 145 ksi yield strength | { | 1018 | 85 | <10 ⁽¹⁾ |
| | | 4140 | 142 | <10 ⁽¹⁾ |
| | | 4340 | 157 | <20 ⁽¹⁾ |
| | | 8620 | 98 | 50 + |
| | | 300M | 106 | 60 + |
| | | ¹ Alloy 25 galled to steel alloy ² Steel alloy galled to Alloy 25 + no galling | | |

Table 8: Galling Resistance of Alloys

| METALS IN CONTACT | | | | THRESHOLD GALLING STRESS (ksi) |
|----------------------|-----|----------------------|--|--------------------------------------|
| Silicon Bronze (200) | vs. | Silicon Bronze (200) | | 4 |
| Silicon Bronze (200) | vs. | Type 304 (140) | | 44 |
| A286 (270) | vs. | A286 (270) | | 3 |
| AISI 4337 (484) | vs. | AISI 4337 (415) | | 2 |
| AISI 1034 (415) | vs. | AISI 1034 (415) | | 2 |
| Waukesha 88 (141) | vs. | Type 303 (180) | | 50 + |
| Waukesha 88 (141) | vs. | Type 201 (202) | | 50 + |
| Waukesha 88 (141) | vs. | Type 316 (200) | | 50 + |
| Waukesha 88 (141) | vs. | S17400 (405) | | 50 + |
| Waukesha 88 (141) | vs. | 20Cr-80Ni (180) | | 50 + |
| Type 201 (202) | vs. | Type 201 (202) | | 50 + |
| Type 201 (202) | vs. | Type 304 (140) | | 15 |
| Type 201 (202) | vs. | S17400 (382) | | 2 |
| Type 201 (202) | vs. | Nitronic 32 (231) | | 2 |
| Type 301 (169) | vs. | Type 416 (342) | | 3 |
| Type 301 (169) | vs. | Type 440C (560) | | 3 |
| Type 410 (322) | vs. | Type 420 (472) | | 3 |
| Type 416 (342) | vs. | Type 416 (372) | | 13 |
| Type 416 (372) | vs. | Type 410 (322) | | 4 |
| Type 416 (342) | vs. | Type 430 (190) | | 3 |
| Type 416 (342) | vs. | 20Cr-80Ni (180) | | 7 |
| Type 440C (560) | vs. | Type 440C (604) | | 11 |
| S17400 (311) | vs. | Type 304 (140) | | 2 |
| S17400 (380) | vs. | Nitronic 32 (401) | | 13 |
| S17400 (435) | vs. | Type 304 (140) | | 2 |
| S17400 (400) | vs. | S17700 (400) | | 3 |
| S17400 (435) | vs. | S17700 (435) | | 2 |
| Nitronic 32 (235) | vs. | S17400 (380) | | 11 |
| Nitronic 32 (401) | vs. | Nitronic 32 (401) | | 34 |
| Nitronic 32 (235) | vs. | Nitronic 32 (401) | | 34 |
| Nitronic 32 (235) | vs. | Type 304 (140) | | 7 |
| Nitronic 32 (401) | vs. | Type 304 (140) | | 13 |
| Nitronic 32 (205) | vs. | AISI 1034 (205) | | 2 |
| Nitronic 50 (205) | vs. | Nitronic 50 (205) | | 2 |
| Nitronic 50 (321) | vs. | Nitronic 50 (321) | | 2 |
| Nitronic 50 (205) | vs. | Nitronic 32 (401) | | 13 |
| Nitronic 50 (321) | vs. | Nitronic 32 (235) | | 8 |
| Nitronic 50 (205) | vs. | Type 304 (140) | | 4 |
| Nitronic 60 (205) | vs. | Type 301 (169) | | 50 + |
| Nitronic 60 (205) | vs. | Type 420 (472) | | 50 + |
| Nitronic 60 (213) | vs. | S17400 (313) | | 50 + |
| Nitronic 60 (205) | vs. | S17400 (332) | | 50 + |
| Nitronic 60 (205) | vs. | Nitronic 50 (205) | | 50 + |
| Nitronic 60 (205) | vs. | S13800 (297) | | 50 + |
| Nitronic 60 (205) | vs. | S13800 (437) | | 50 + |
| Nitronic 60 (205) | vs. | AISI 4337 (448) | | 50 + |
| Nitronic 60 (205) | vs. | Stellite 6B (415) | | 50 + |
| Nitronic 60 (205) | vs. | A286 (270) | | 49 + |
| Nitronic 60 (205) | vs. | 20Cr-80Ni (180) | | 36 |
| Nitronic 60 (205) | vs. | Ti-6Al-4V (332) | | 50 + |

Values shown are unlubricated threshold galling stress (ksi) for the button and block galling test. Values given as 50+ indicate the samples did not gall. Numbers in parentheses following alloy designations are nominal hardness (Brinell).

Table 9: Galling Resistance of Stainless Steels

| Block Material | Condition & Nominal Hardness (Brinell) | Button Material | | | | | | | | | |
|----------------|----------------------------------------|-----------------|------|-----|------|------|------|-----|--------|-------------|-------------|
| | | 410 | 416 | 430 | 440C | 303 | 304 | 316 | S17400 | Nitronic 32 | Nitronic 60 |
| Type 410 | Hardened & Stress Relieved (352) | 3 | 4 | 3 | 3 | 4 | 2 | 2 | 3 | 46 | 50 + |
| Type 416 | Hardened & Stress Relieved (342) | 4 | 13 | 3 | 21 | 9 | 4 | 42 | 2 | 45 | 50 + |
| Type 430 | Annealed (159) | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 36 |
| Type 440C | Hardened & Stress Relieved (560) | 3 | 21 | 2 | 11 | 5 | 3 | 37 | 3 | 50 + | 50 + |
| Type 303 | Annealed (153) | 4 | 9 | 2 | 5 | 2 | 2 | 3 | 3 | 50 + | 50 + |
| Type 304 | Annealed (140) | 2 | 24 | 2 | 3 | 2 | 2 | 2 | 2 | 30 | 50 + |
| Type 316 | Annealed (150) | 2 | 42 | 2 | 37 | 3 | 2 | 2 | 2 | 3 | 38 |
| S17400 | H 950 (415) | 3 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 50 + | 50 + |
| Nitronic 32 | Annealed (235) | 46 | 45 | 8 | 50 + | 50 + | 30 | 3 | 50 + | 30 | 50 + |
| Nitronic 60 | Annealed (205) | 50 + | 50 + | 36 | 50 + | 50 + | 50 + | 38 | 50 + | 50 + | 50 |

Values Shown are unlubricated threshold galling stress (10^6 psi) for the "button and block" galling test. Condition and hardness apply to both the button and the blank material. Tests were terminated at 50×10^6 psi, so values given as 50+ indicate the samples did not gall.