Friction Welding And Its Applications In Today's World

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Abstract : By developing technology of today, the necessity of using different materials by joining came out. The most suitable method in joining two different alloyed steel is to weld. The fact that the properties of welding zone are naturally different from the properties of steels in different alloyed at post welding process has came up and these differences occur some important problems. Among many kinds of welding methods, using the melting welding methods has also increased the number of these problems. However, in the connecting zone, many different zones come out by depending on composition and properties of the connecting materials. Deposite remain of the melting welding methods, welding faults of porosity and inside tightens of cooling are the important disadvantages of these methods and they decreases the strength of welding. For this reason, solid state welding methods are more suitable due to these melting welding faults. The most important and applicability of these methods are friction welding. For these reasons, in this study importance and application areas of friction welding were explained.

1. Introduction

The ideas of using heat obtained by friction in welding and forming of materials are not new. Friction welding obtained by frictional heat is a commercial process, which has found several applications in different parts of the world with the advancement in technology. First, simple devices having lathe machine type and metal rods have been used in butt welding trials. However, these studies can onl be regarded as preliminary technical trials with little practical importance. The firts trial of friction welding goes back to the 15th century and the first patent was granted to J.H. Bevington, who then was a machinist. Bevington first applied friction welding in elding of metal pipes. Friction welding which was first applied to cutting tools in metal processing industry has found several applications. W. Richter patented the friction welding process in 1924 (in England) and 1929 (in Germany) and H.Klopstock patented the same proces in the USSR (1924). H. Klopstock and A.R. Neelands obtained a patent for friction welding of cylindrical parts. Studies on welding of plastic materials were carried out in the 1940s in the USA and Germany [1, 2]. A Russian machinist named A. J. Chdikov has realized scientific studies and suggested the use of this welding method as a commercial process. He has successfully done a welding process between two metal rods and patented this process in 1956. Vill and his colleagues have further investigated the process with a number of studies. Researchers of American Machine and Foundry Corporation named Holland and Cheng have worked on thermal and parametrical analysis of friction welding [3]. By the way, the first studies of fricton welding in England were carried out by the Welding Institute in 1961. By modifying the friction welding, the Caterpillar Tractor Co. in the USA developed the method of inertia welding in 1962. After this study, conventional friction welding has been regarded as the Russian type process and inertia welding as the Caterpillar type process. With these advances, applications of friction welding have found several applications throughout the world. Friction welding is one of the most widely used welding methods in the industry after electron beam welding [4].

This study addresses friction welding, its significance and types, welding capability, welding parameters and their applications.

2. Friction Welding

All welding methods can be investigated in one of the two main categories; melt and pressure welding. Friction welding is a type of pressurized welding method. Friction welding is a solid state process, where no electric or other power sources are used, mechanical energy produced by friction in the interface of parts to be welded are utilized. Using heat efficiently in the welding region is only possible by efficiently distributing heat on surfaces, to which welding will be applied. During the welding process, surfaces are under pressure and this period called the heating phase continues until plastic forming temperature is achieved. The temperature in the welding region for steels is between 900 and 1300 ^{o}C. Heated metal at the interface accumulates by incerasing pressure after heating phase. Thus, a type of thermomechanical treatment occurs in the welding region and this region has stable particle structure. Metals and alloys, which cannot be welded by other welding methods, can be welded using friction welding. In order to obtain welding connection between parts, untreated surfaces need to be contacted to one another. This contact is efficient because friction corrects contacting problems. The melting process does not normaly occur on contacted surfaces. Even though, a small amount of melting may occur, accumulation caused by post-welding process makes it invisible. Figure 1 gives the stages of friction welding. One of the parts is stationary while the other one rotates (Figure 1_1). When the roational speed rises to a certain value, axial pressure is applied and locational heating occurs in parts at the interface. Then, rotation is stopped, heated material at the interface accumulates (Figure 1_3) [5, 6]. The stages of friction welding during the welding process are given in Figure 2 [7].

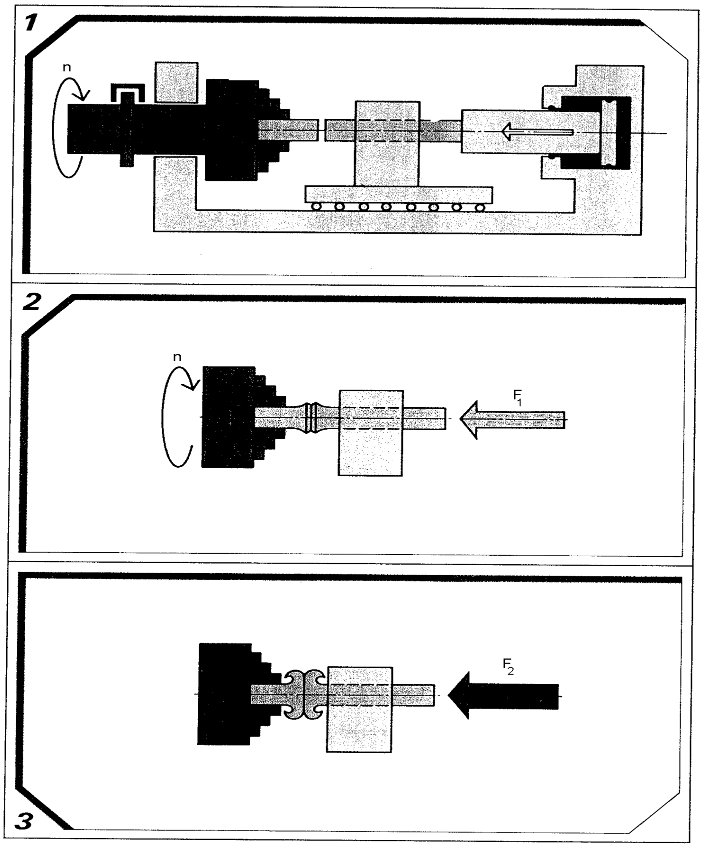


Figure 1. The schematic stages of friction welding [7].

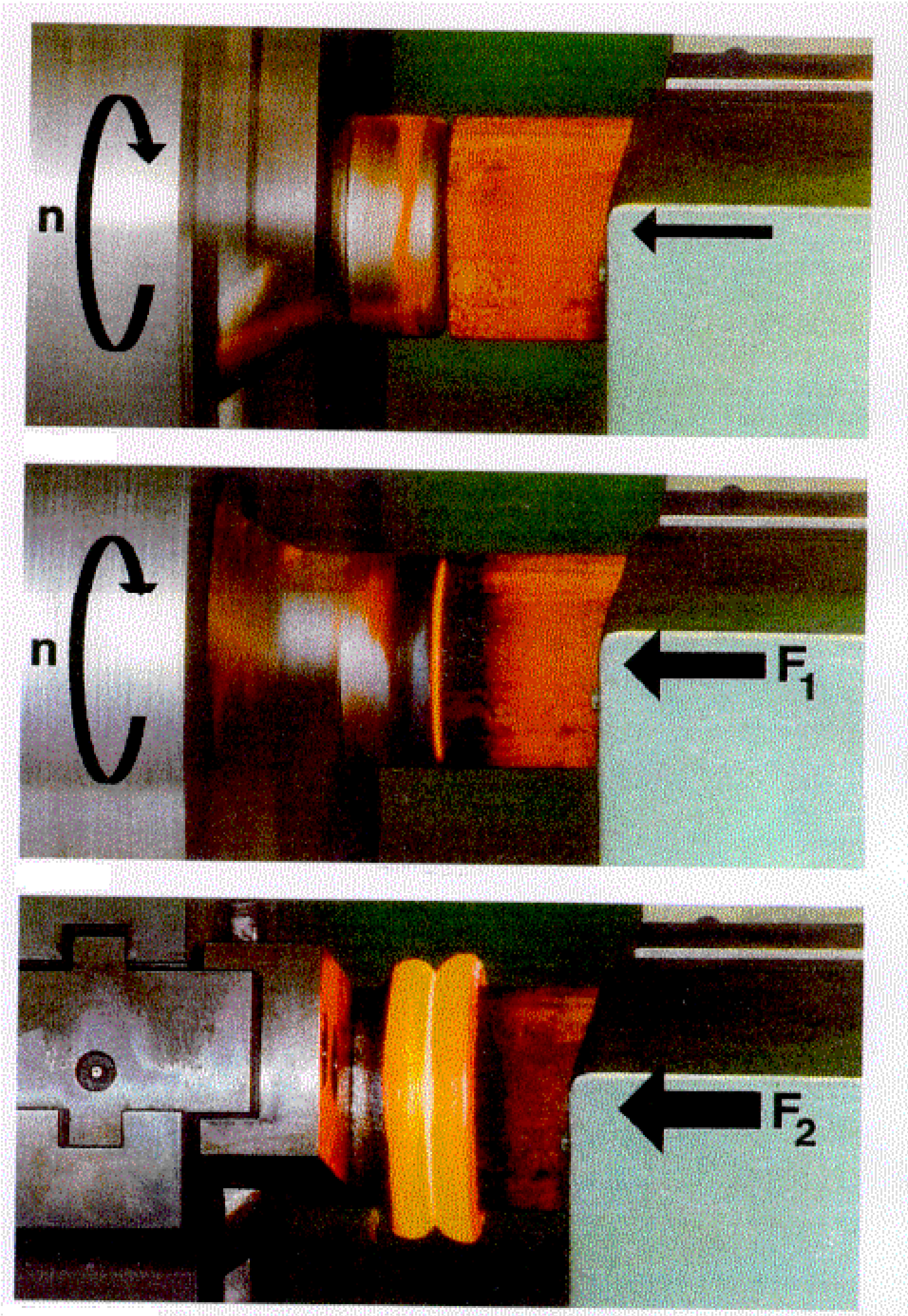


Figure 2. Actual look of friction welding process [11].

Applications of friction welding are generally used in the welding of pipes and circular rods. The basic movement in this kind of application is the rotational movement causing friction [8]. Figure 3 shows conventional friction welding methods in joining of certain size rods and pipes.

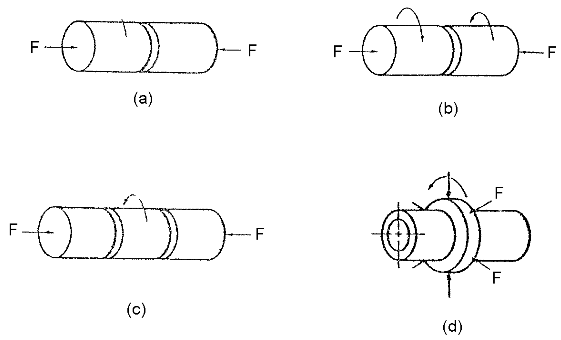


Figure 3. Applications of friction welding [9, 10].

Figure 3-a shows the most simple and used application. In this application, the axes of parts to be welded are the same and rotate around other axes. Under the rotational pressure, friction forces occur on cotact surfaces. Figure 3.b suits best to the small size samples requiring higher rotational speed. It is used in applications where higher relative rotational speeds are required. Figure 3.c is for the applications where parts being very long are efficiently joined. Even though it could not find widespread applications, Figure 3.d is mainly used in welding of pipes rotating under radial forces [9, 10].

It needs to be known that a high quality welding connection can only occur in parts having claen and smooth surfaces. Several inclusions, oxides formed on the surface, films absorbed by the surface are always present and negatively affects bond formation and welding quality. These problems are removed from welding connections by wearing off surfaces during friction [8].

In friction welding, orbital movement as well as rotational movement, linear vibration movement and angular vibration movement can be applied. Orbital movement is fr the welding of non-cylindrical parts. Application shown in Figure 4 is between a stable part and a part rotating circularly [5].

Figure 4. Friction welding including orbital movement [5].

One of the parts in figure 5 moves forward and backward in linear vibration movement. This method has firs been suggested by Vill. In angular vibration movement, one of the parts makes an orbital movement under applied pressure [3].

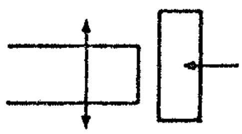


Figure 5. Friction welding including linear rotation movement [3].

2. 1. Types of Friction Welding

Friction welding can be applied by using one of the two methods depending on the source of mechanical energy. With current advances, a combined welding method including both of the methods aforementioned has been developed. These are continuous driven friction welding, flywheel driven friction welding and a combination of the two [1, 5].

2.1.1. Continuously Induced Friction Welding

A inducement driven group provides the necessary energy for rotation. Mechanical energy is converted to heat by applying pressure from rotating part to non-rotating part. This method is generally mentioned in the literature for friction welding. One of the parts is connected to the engine inducement unit and rotates at a constant velocity; a constant axial force is applied to parts. Working parts interact with each other during welding or until axial shortening occurs. Then, braking system stops the process. Pressure applied during welding is increased and stays at a certain value until weld cools down. The essential welding parameters are rpm, friction force on the surface, the length of friction period, forging force and forging time [1, 5].

A schematic of continuous inducement friction welding machine is given in Figure 6 and process parameters in Figure 7.

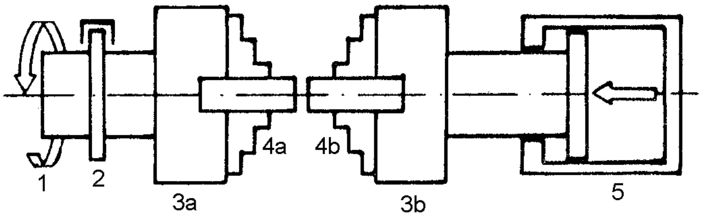


Figure 6. A schematic of continuous inducement friction welding machine [1, 5].
(1.Inducement engine, 2. Brake 3 a. Spindle of rotating working part, 3 b. Spindle of stationary working part, 4 a. Rotating working part, 4 b. Stationary working part, 5. Accumulation cylinder)

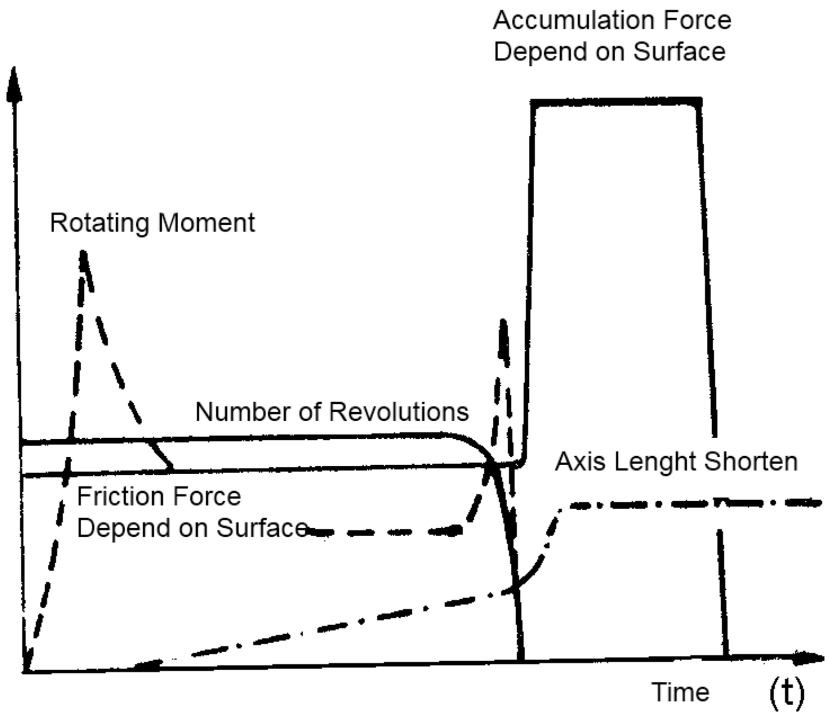


Figure 7. Process Parameters versus time in friction welding [1, 5].

2.1.1. Flywheel Induced Friction Welding

In this welding method, flywheel induced system constantly rotates and is joined to flywheel shaft system to achieve a certain speed. After reaching a certain speed, engine flywheel is separated from shaft flywheel. Shaft flywheel having a low moment of inertia stops without braking. Therefore, this welding method is known as welding of inertia in the literature. One of the parts is connected to the flywheel and accelerates at a certain speed and thus mechanical energy is stored in the flywheel. Then, the two parts are contacted and a certain welding pressure is applied. Parts under this pressure interact with each other and energy stored in the flywheel is spent for friction. The speed of flywheel decreases as welding region heats up. In some circumstances, pressure is increased before flywheel completely stop and the effect continues for some time. Flywheel induced friction welding has better seam, narrower ITAB region, better serial production, lower power need and more simple apparatus than continuous induced friction welding. The essential welding parameters are rpm, forging force on the surface, the mass of flywheel, and forging time [1, 5].

A schematic of flywheel induced friction welding machine is given in Figure 8 and process parameters in Figure 9.

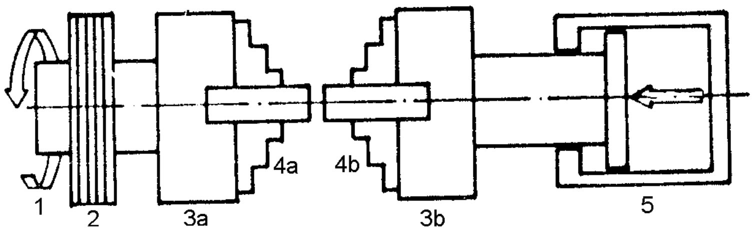


Figure 8. A schematic of flywheel induced friction welding machine [1, 5].
(1.Inducement engine, 2. Changeable Flywhell, 3 a. Spindle of rotating working part, 3 b. Spindle of stationary working part, 4 a. Rotating working part, 4 b. Stationary working part, 5. Accumulation cylinder)

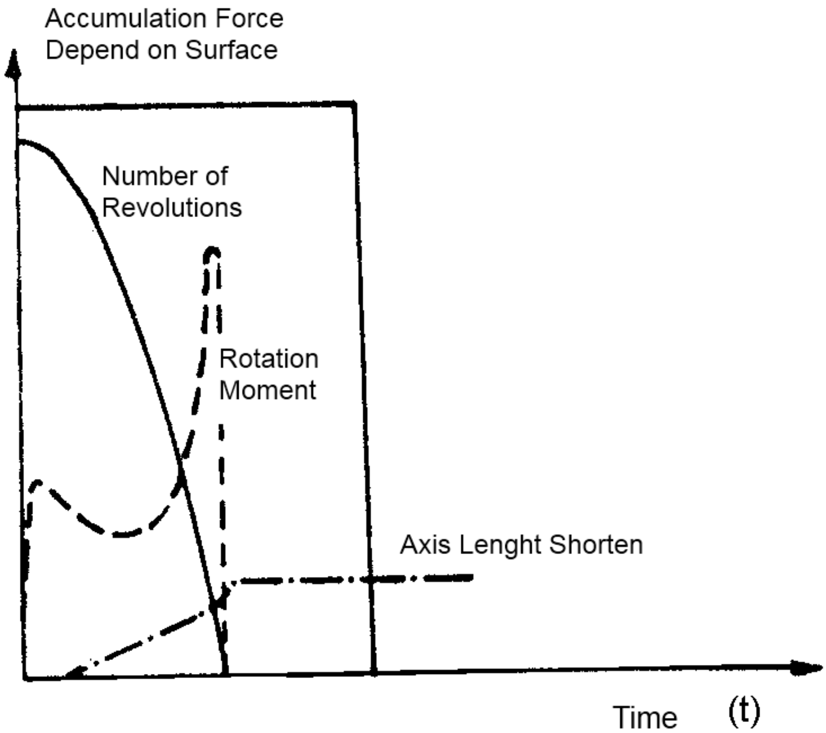


Figure 9. Process Parameters versus time in flywheel induced friction welding [1, 5].

2.1.3. Combined (Hybrid) Friction Welding

This method is a combination of aforementioned the two methods of friction welding. It has advantages in joining parts with high capacity. This method is also sometimes termed as flywheel induced friction welding. The essential welding parameters are rpm, friction force on the surface, the length of friction time, and forging time on the surface, forging time and time of brake [1, 5]. Process parameters for the combined friction welding is given in Figure 10.

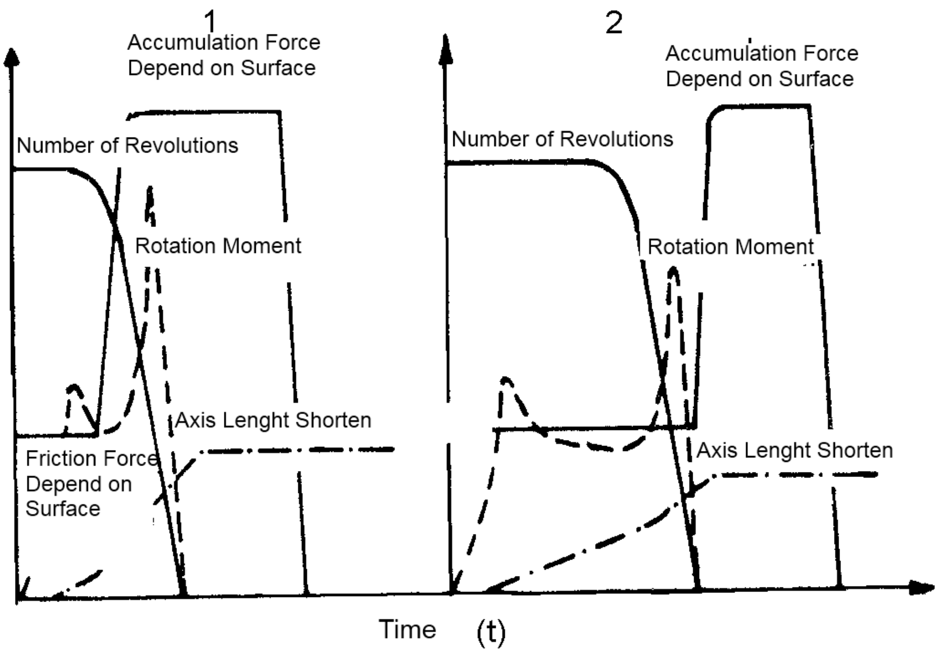


Figure 10. Process Parameters versus time in combined friction welding [1, 5].

The process of welding includes friction and accumulation stages as given in Figures 7, 9, and 10. Moment curves are essential to understanding of process parameters in all the welding methods studied. Dry friction between parts exists in the beginning of process and moment curve stabilizes after reaching the maxima.

Naked surface interactions increase due to disintegration of oxide layers among contacted surfaces and strong atomic bonding occurs as a result of these interactions. These bonds are forced to be broken due to friction. However, strong adhesion forces occur, moment increases and temperature reaches to the desired level. Velocity decreases quickly due to braking and moment becomes zero [1, 5].

2.2. Expected Properties of Friction Welding Machine

Friction welding machines are generally similar to lathe and drill. The first friction welding machines are modified forms of these machine tools. The schematic of friction welding machine is given in Figure 6 or Figure 8. As can be seen from the figures, a friction melding machine has the main body, joining parts, rotate and accumulate mechanisms, brake system, power supply, control unit and control panel. Fricton welding machines are all-mechanized machines. Joining and releasing of parts, turning of capaklar produced due to accumulation after welding are automatically accomplished. The main functions in friction welding are joining, compressing and releasing of parts, rotation and friction under pressure, braking, accumulation and meticulous adjustments of required processing times.

Sample joining apparatus needs to have a certain rigidity, must resist increased moments, must eliminate vibrations and leaks. Especially, possible vibrations during welding process need to be taken into account while designing the friction welding machine. In addition to vibrations, other radial and axial forces have to be accounted for. Therefore, joining apparatus has to have a design which will counter compressing forces. For this process, V type two chaps or special chaps are used [6].

All stopping apparatus used to hold friction equipment must be highly dependable. A slight deformation in parts to be joined may result in a low quality welding and may also damage brake system. Brake systems automatically centerd are used in most of the applications. Friction welding machines have certain particle size and material limitations. For example, a machine having 120KN compressed force and 15KW electric engine can be used in the welding of stells with cross-sectional areas of 130-800mm^2. All machines can be adjusted to meet certain specifications and can automatically be controlled. This process is sometimes done by just manually turning off the switch or protectors [11].

2.3. The Suitability of Friction Welding and Friction Welding Capability of Materials

Knowledge on material properties and applicability of metallic materials and material combinations for friction welding is not completely clear. Experimental studies and practical applications have been giben to address this problem. Preliminary trilas have been carried out in order to determine optimum parameters of welding, the applicability of welding process for every new material or material combinations. The results of these studies are not concrete since they are experimental. They can be modified or redefines as new facts come out [12, 13].

The citeria needed for other welding methods are not valid for friction welding because friction welding is applied to materials which can not be processed with other welding methods [10].

The strength of a material and its deformation capacity under heat are the two parameters needed for the test of suitability of a material to welding. The strength of material has to be high enough to resist axial pressure and torque, which may occur due to excessive deformation. Morover, the material to be joined needs to exhibit enough heat treatment deformation behavior for the quality of joining process [12].

Materials and their combinations can be categorized into two groups depending upon the characteristics of materials to be joined. The first group of materials are the ones showing the same type of heating behavior and the second group includes materials having different hor material strength and melting temperatures. The direct welding process is applied to the first group of materials. But, preliminary trials are carried out for the second group of materials before applying welding process [10].

Several iron based and non-iron materials can be joined using the friction welding. In addition, friction welding can be used in joining of metals exhibiting different thermal and mechanical properties. Most of the time, these materials can not be processed using conventional welding methods. Friction welding method is more preferred than any other conventional welding method because metals can be joined at temperatures lower than their melting point and welding time is a lot shorter. Friction welding of metals having different thermal amd mechanical properties causes asymmetrical deformations. A higher welding strength is generally achieved for the materials giving symmetrical deformations. To achive this, Vill suggested a 15 to 25% increase in ductile parts during the welding process [11].

Any material not having good friction properties but forgable with friction welding can easily be welded. Alloy elements supplying dry oiling prevent the joining section from reaching welding temperature.

Ferrous based material from soft steel to high alloyed steels can be processed using friction welding. Steels with lower strength can be more easily joined with a large parameter range. High alloyed steels, on the other hand, requires critical processing parameter range and higer axial forces. Heat-treated stainless steels can be welded in a more sensitive parameter range just as in high alloyed steels. For high alloyed steels, higher forces on the surface and long friction time are needed due to their lower deformation capability. Especially for “air watered steels”, a suitable ITAB region is required to minimize cooling rate of welding region. Since crack formation is very fast in high strength materials, joined surfaces have to be rid of crack effects [11].

Sintered materials, Al, Cu, Ti, tr, Mg alloys, heat resistant Ni and Co alloys and refractory materials such as Ta and Mo alloys can successfully be joined by friction welding [13].

- Austentistics steels due to their higher ductility and heat deformation capability need lower friction time and pressure,

- Higher stregh alloys due to their lower heat conductivity and higher heat strength capability need higher friction time and lower friction pressure,

- Cu, Al, Ti and their alloys are subjected to friction welding at higher rpm and lower friction pressures.

A successful friction welding can not be achived in some metals and alloys due to their inherent metallurgical properties.

These are as follows:
- All pig iron due to its friction temperature limitation caused by free graphite,
- bronze and grass having Pb concentration of more than 0.3% and automat steels having S or Pb concentrations more than 0.13%,
-highly anisotropic materials due to their high fractureability in the transtition region
-materials having graphite, Mn, S and free Pb in their structure [10, 13].

2.4. Preparation of Materials for Friction Welding and the Design

Parts to be processed using griction welding method have different design considerations from those processed with conventional welding methods. Paint, oil and other impurities do not pose a problem in friction welding. Though not preferred, surfaces cut by oxygen can be welded. Moreover, additional layer on the surface such as corrosion layer does not affect welding process. However, thick oxide layers, pin sand needles on the surfaces, deep cuts and holes habe to be avoided. A poor heat distribution may occur if too many indent and bulge are present. Bulges behave as bracket beam when surface roughness is very high. Inner layers occur and addition layers occur even with deformation because root (base) structure is cold. Deformation in welding region must remove these structures. In addition, surface pre-teratment of different metals and alloys is significant. A special form of a material on surfaces to be weld is not needed as in the case of traditional welding processes. However, spherical or conical mouth may be necessary in high diameter parts to assit in friction. Mininum axial loss is required in parts to be welded. The tolerance of welding depens on not only defects in working parts but also the welding machine itself [12, 14]. The tolerance value for lenth is given as 0.203 mm. Begg and Humpreys have reported 0.2mm axial KACIKLIK tolerance and 0.001 rad angular tolerance [15].

Basic design of friction welding includes rod-rod, pipe-pipe, pipe-sheet, rod-sheet and pipe-disc combinations. Based on friction welding theory, at least one of the parts has to be able to rotate. Mixed type parts and difficult to be forged parts can be joined using more than one friction welding machine. The angular range in friction welding is given to be between 30 and 45 or 45 anf $60^{0.}$ D. L. Kuruzar suggested an angle more than 30°. In some of the designs, welding joints are specifically designed to account for problems in removing metal parts after welding [14].

2.5. Parameters of Friction Welding

Apart from traditional welding methods, several welding parameters can be controlled in friction welding. These parameters include diameter of experimental rod, rpm of the part, rpm of parts in to lathe, friction contact time, forging delay time, forging time, time of increased friction pressure, friction pressure. Moreover, other parameters such as geometry of parts and material properties are also significant. The rpm of rotating parts, friction time, friction pressure, forging pressure and time are the parameters needed to be take into account while optimizing the welding process. A successful welding process can occur if parameters are optimized [8].

The lower rpm of roating parts causes enormous moments and nonuniform heating results in. On the other hand, lower rpm values minimize formation of intermetallic compounds. With higher rpm of rotating parts, ITAB widens, and power supply is not affected. To prevent overheating in the welding region, friction pressure and friction time have to be carefully controlled.

Pressure values applied in welding is very significant bcause it controls temperature gradient and affects rotoational torque as well as power.

Friction and forging pressure are directly related to geometry and material properties of parts to be welded and have a wide range.

Over applied pressure values increase power needs accordingly. Due to increased energy input, higher pressures decrease the width of ITAB, accelerate metal displacement ratio and reduces welding time resulting in heat band on the boundary. The variable of pressure can be controlled by the temperature in welding region and decrease in axial length. Optimum pressure must be applied to materials in order to get uniform deformations throughout [13].

Friction pressure has to be high enough to allow the removal of oxides, to get uniform heating throughout and to interrupt the affinity between surfaces and the air. The application of forging pressure especially during friction process improves welding properties.

Forging pressure depends on the heat yield stress of the material. It should neither be high enough to cause welding accumulation nor is it low enough to cause under welding. Forging pressure in some materials are determined depending on the lower strength material. The diffusion of macro particles from surfaces to surfaces occur during forging. Bonds continuously form and break down during friction at interface locations. In the beginning of forging maximum bonding have to occur on the surface because permanent bonds are these lastly formed bonds. Parts need to interact with each other under pressure and this pressure should not be reduced until welding heat cools down. [11].

Friction and forging times are directly related to material properties. The friction time should allow plastic deformation to occur or remove possible residuals and particles. For a high quality welding joint, minimum friction time needs to be exceeded. Lower friction times as well as nonuniform heating result in nonjoined areas at the interface and inadequate plastic deformation. This brings the problem of low quality weld. Higher friction times, on the other hand, causes rough structure and wide ITAB region formation. This is especially important to the welding of different materials because poor mechanical properties may be obtained due to formation of undesirable substances. Moreover, overheating and material loss are also possible [13].

2.6. Applications of Friction Welding

This method is especially useful for the serial production. Relatively high overhead cost is balanced with higher production rate and lower labor requirement. Process has several dimensions and hardware could easily be adjusted. Thus, the method also becomes useful for the production of relatively smaller parts. With these advantages, friction welding has found widespread application in the industry. Friction welding can generally be applied in the following industries with listed applications:

-Machine production and spare part industry: cogwheels, piston rods, hydraulic cylinders, radial pomp pistons, shaft with worm screw , crankshafts, drill bits, valves.

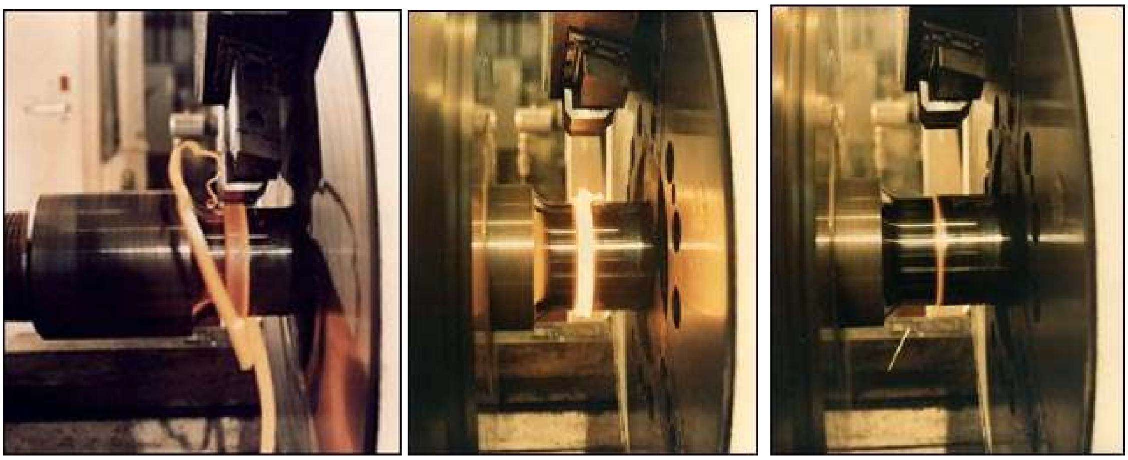
-Automative industry : valves, clack valve, drive shafts, gear levers, axle fasteners, break spindles, transmission mechanisms, preheat rooms, pipe spindles, banjo axles.

- Aviation and space industry: repulsion jets, combustion chambers, spindles, turbines, rotors, pipes, fittings, flanges.

- Work set industry: Spiral drills, milling cutters , borers, reamers, cutting tools.

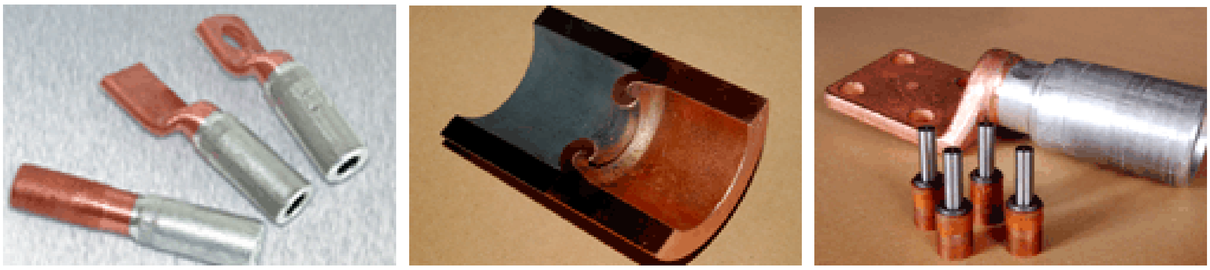
- Electrical, electronics, and chemical industry: receiver camera for gas analysis, segregation columns forchromatograph, Electrical connectors, continuous solder top, swing contacts, pipe fittings [16].

2.7. Some Examples of Applications of Friction Welding



Phase 1 **Phase 2** **Phase 3**

Phase 1: Low temp interface heat cycle by spinning one component against another stationary component.
Phase 2: Solid forging cycle showing displaced plastic state material when final axial forging force is applied.
Phase 3: Plastic state flashing is removed easily, even for hardenable materials that would otherwise require grinding [17].



Electrical connectors

Air bag canisters

Gear levers

Stanley tools

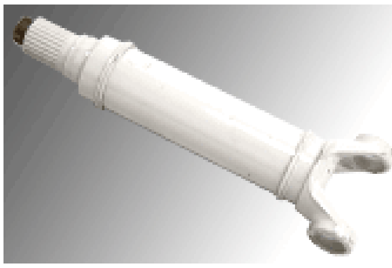
Airbag component

Drill bits

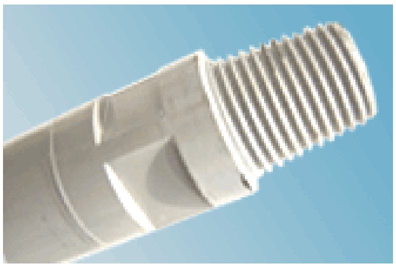
Engine valves

Pump shafts

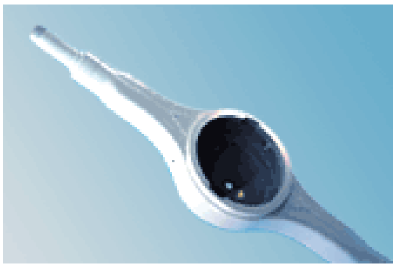
Piston rods



Drive shafts



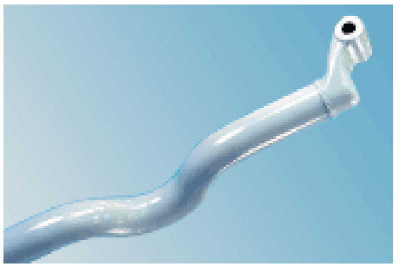
API drill pipe



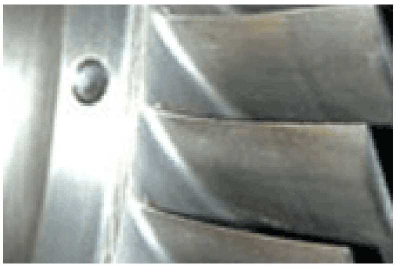
Truck banjo axle

Gear cluster

Track roller



Bent axle



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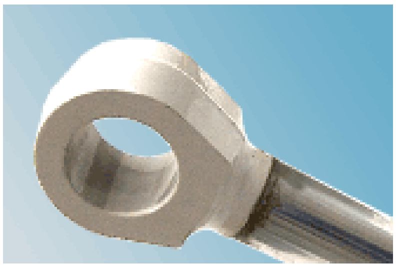

Large piston rod

Hydraulic cylinders

[18].

2.8. Advantages and Disadvantages of Friction Welding

Friction welding has better technical and economical properties than conventional welding methods. Friction weldinfg is generally compared to electrical resistance welding. However it can also be compared to other welding methods such as electron beam welding and electrical arc welding. [11].

- One of the main advantages of friction welding is lower energy requirement.
- The process has unusual high yield and lower energy requirement and power supply. Moreover, power requirement of friction welding is about one tenth of electrical resistance welding (Figure 11). Friction welding causes triphase in the engine and the power factor is Cos φ = 0.80-0.85. However, electrical resistance welding is one phase process and the power factor is Cos φ = 0.40- 0.60.

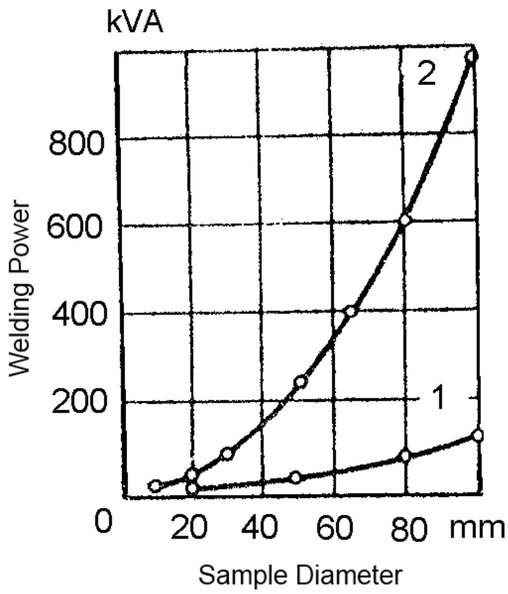

Figure 11. The power requirement during welding for different welding methods (1. Friction welding 2. Electrical resistance welding).

3. Results

- Cooling time is very short because the amount of heated metal during friction welding is very small. The timeframe ranges from several seconds to several minutes. This allows us to achieve friction welding at very high speeds (only comparable to electrical resistance welding).

- Heat in friction welding occurs in welding region and is distributed to the surfaces of parts to be welded. However, heat loss is very high in other conventional welding methods because heating is applied to the all material in a nondiscrimating manner.

- Material loss during friction and forging is minimum making the friction welding a viable economic alternative.

- Surface preparation is minimum and the process does not produce vast amount of waste and a high quality seam is obtained.

- Friction welding can be considered a serial method since the process is very fast.

- The control of parameters affecting welding quality is very easy and is easily accomplished.

- Friction welding system can also bea automated easily.

- Since friction welding is a solid state welding method, no slack and waste are present.

- The efficiency of the process is very high because several parameters including axial load, speed of rotation and YIGMA amount can easily be controlled.

-The disadvantages include geometrical limitations of parts, excessive material accumulation and the need for its removal, and higher capital cost.

Table 1 lists the comparison of several welding methods in terms of material and process variables.

Property	Friction Welding	Electron Beam Welding	Electrical Resistance Welding	Electrical Arc Magnetic Active Welding
Material to be welded	✔	-	-	-
Crossectional area	✔	-	-	-
Welding geometry	-	✔	✔	-
Preparation of parts	✔	-	-	-
Accretion of Weld Materials	-	✔	-	-
Additive ofMaterials	-	✔	-	✔
Compatibility Cross Section to Welded Joint	✔	-	-	-
Process Control	✔	-	-	-
Accounting Rate of Return	-	-	✔	-

Table 1. Comparison of Different Welding Methods (13)

4. References

1. Bahrani, A. S., Crossland, B., 1976, Friction welding, CME, 61-66.
2. Duffin, F. D., Crossland, B., 1971, Friction welding with sudden relase of the fixed component, Advances in welding processes, Solid phase joining processes, proceeding of the conference, The welding Institute, Abington Hall, Cambridge, 25-33.
3. Vill, V. I., 1962, Friction Welding of Metals, AWS, Newyork
4. Wang, K. K., Lin, W., 1974, Flywheel friction welding research, Welding Journal, 233-241.
5. Welding Handbook, 1980, Resistance and solid state welding and other joining processes, AWS, Miami, 58-76, 239-262.

6. Nicholas, E.D., 1983, Radial friction welding, Welding Journal, 17-29.
7. KUKA kaynak makinasi ürün kataloğu,1990.
8. Anık, S., 1983, Kaynak Teknolojisi El Kitabı, Ergör Matbaası, İstanbul, 259-269.
9. Tylecote, R. Y., 1968, The solid phase welding of metals, Edward Arnold (Publisher) Ltd., London, 1-150.
10. Yılmaz, M., 1993, Farklı takım çeliklerinin sürtünme kaynağında kaynak bölgesinin incelenmesi, Doktora Tezi, Y.T.Ü., 1-55, İstanbul.
11. Uzkut, M., "Yüksek Alaşımlı İki Farklı Çeliğin Sürtünme Kaynağı İle Birleştirilmesinde Optimum Kaynak Parametrelerinin Tesbiti ve Birleşme Bölgesinin İncelenmesi", Doktora Tezi, C. B. Ü. Fen Bilimleri Enstitüsü, 1999, Manisa
12. Ganowski, F. N., 1973, Practical considerations for friction welding, Welding Engineering, 40-44.
13. Metals Handbook, 1983, Welding and brazing, ASM, Metals Park, Ohio, 557-580, 719-728.
14. Kuruzar, D. L., 1979, Joint design for the friction welding process, Welding Journal, 31-35.
15. Begg, G. H. C.,Humphreys, B.A., 1981, Rotational – friction welding, Engineering, Tech. File no 91, 1-4.
16. Ellis, C., R., G., 1976, Friction welding: where industry uses it, Welding Design and fab., 78-81
17. http://www.nctfrictionwelding.com/process.php
18. http://www.thompson-friction-welding.co.uk