An Approach to the Design Analysis for continuous Drive Friction Welding Machine.

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Friction welding (F.W) is a process to successfully join a wide variety of similar and dissimilar metal rods with high energy efficiency. Various ranges of the F. W. machines are now in use in various parts of the world. In India, some automobile manufacturing industries use imported Friction Welding machines. The indegenous machines are yet to be developed. this article deals with the design analysis and scope of indegenous development of Continuous Drive F. W. machines.

INTRODUCTION

Friction welding is a method for making cold welds of components which have relative motion under contact pressure. The mating components under relative motion and pressure produce heat at the interfaces. The weld is completed by the application of forging during or after cessation of relative motion.

Most of the metals and alloys generally can be friction welded. Good welds with adequate amount of desirable mechanical properties such as fatique and bending strength, impact toughness etc. can be obtained to the desired extent by suitable control of parameter such as contact pressure, relative motion, duration of motion etc., during welding. F. W. joints resemble the joints produced by flash and upset welding, but F.W. joints are superior to other types because heat generated during rubbing action in the region directly along the surface of the pieces to be welded is utilised to the maximum extent and the weld quality is excellent. With all its advantages, one serious limitation is, of course that the work piece must have an axis of symmetry. The friction welding is mainly used for circular section. For other shapes it is yet to be developed. The cross sectional area of the pieces to be welded is another constraint. Welding of solid pieces above 200 mm dia. requires large amount of frictional torque and upsetting force and these are to the tune of several hundred metric-tons and tons respectively and consequently equipment of large capacity is needed.

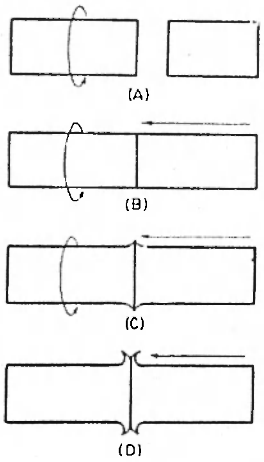
A list of products used in engineering applications are given :

- High quality low cast I. C. engine valve. This is made of heat and corrosion resistant steel valve body and low alloy wear resistant stem.
- Carbon steel to stainless steel joints for manufacturing shafts for motor mounted cryogenic and chemical pumps.
- Joints of nickel based alloy impeller to steel shaft for turbo-blower of gas turbine unit.
- Joints of copper to aluminium for transition pieces used for taking tapping from aluminium cables. These are used in electrical distribution/transmission systems.
- Steering shaft and worm gear assembly of automobiles.
- Piston rod assembly of heavy duty auto and diesel engines.
- Camshafts, crankshafts and axles of varying dimensions for light passenger and bulk load carrying vehicles.
- Pre-combustion chambers of varying dimensions for diesel engines & high speed steel and ductile steel joints for tools such as drill reamers, milling cutters, broaches etc.

If various sizes of friction welding machines & and its products are made available in the country, reduction of import bill will result. Therefore, an attempt has been made in this article to deal with design considerations for developing various ranges of continuous drive F. W. machines.

PROCESS REQUIREMENT

The basic steps in friction welding are shown in Fig. 1.



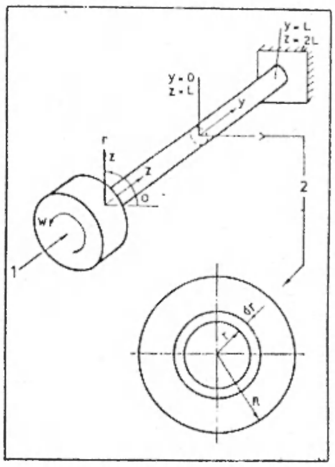


Fig. 1: Basic steps in Friction Welding

Fig 2 : Co-ordinate notation for frictionn welding heat transfer analysis i. Axial Load ii. Interfe Load

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The welding cycle may be divided into two phases.

(a) The rubbing or friction phase.
(b) The upsetting or forging phase.

The welding heat is developed during the friction phase and the weld/joint is consolidated during the forging phase. The main function of the heating phase is to raise interfacial zone of the materials to be welded to an elevated temperature so that, the resistance to yielding is low. Then forging phase proceeds to achieve an atomic bonding. Rotational speed, heating pressure and heating time are the three important parameters that influence the metallurgical and mechanical properties of the welded joints.

Speed : Friction heating requires peripheral velocities between 1-3 m/sec to make quality welds of materials. Therefore, smaller diameter specimen requires higher rotational speed (6000 rpm for 3.0 mm dia. M.S. rod) and large diameter specimen requires low speed (300 to 700 rpm for 75 mm dia M. S. rod).

Axial pressure : The axial pressure which controls the temperature gradient at the weld zone, drive power and the amount of the metal to be displaced depend upon the joint geometry and the type of material for joining. The pressure should be high enough to protect the joint interface from contamination by keeping the two surfaces in intimate contact.

Heating time : The heating time is generally determined by experimental analysis. Longer heating time usually result in lower productivity and wastage of materials whereas insufficient time causes irregular heating with oxide inclusions and unbonded areas at the interface.

Bonding mechanism : When similar metals make contact under pressure a strong adhesion & mechanical interlocking takes place at the various points of contact. During relative motion under pressure the adhered joints are destroyed and the metal transfer takes place from one surface to other. As rubbing motion continues the temperature at interface zone rises and it becomes plastic. The plastic metal forms a continuous layer and is mostly forced out from the interface. Axial shortening continues as the heat and the pressure are maintained. The continuous plastic interface gets consolidated due to diffusion bonding under pressure once the heating/rubbing is withdrawn.

ANALYSIS

Torgue characteristics : The torgue during the friction/heating phase increases at a faster rate initially as shown in Fig. 3 and after reaching a peak, the torgue reduces at a faster rate to a steady and stable condition. This torgue cycle usually divided into four phases. The first phase corresponds to the period when seizure of the micro projections of the surface over the contact surface takes place. In this phase the friction torque rises with fluctuation and rapidly reaches the peak. In the second phase the frictional heat flows into the base metals from the seizuring parts and soften. The heated zone continuous to thicken and friction torgue gradually decreases.

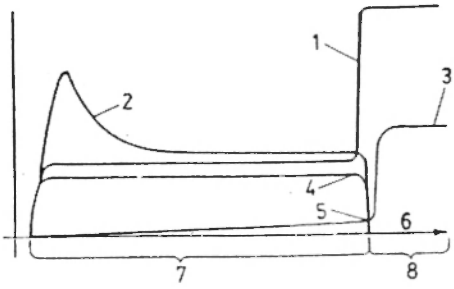

Fig 3 : Typical profiles for basic friction welding process
1. Axial Pressure 2. Interfacial Torque (M) 3. Total Upset
4. Relative Surface Speed (W) 5. Total Burn-off 6. Time
7. Heating Phase 8. Forging Phase

In the third phase the rate of heat generation by friction and the rate of heat conduction into the base metals reaches an equilibrium state and due to which the rate of deformation of the plastic zone and the friction torgue remains ot a lower steady level. In the fourth phase the friction torgue rises slightly due to reduction of plasticity and then falls with the decrease of rotational speed returning to zero. The basic friction welding torgue and power profile are shown in Fig. 4.

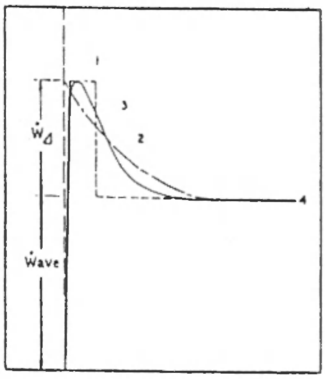

Fig 4 : Basic friction welding power profile charecteristics
1) Maximum power input max = Wave + W_Δ 2) $W_{\Delta_e} \lambda t$
3) Actual power profile 4) Wave

Heat liberation during friction phase : Heat generated may be determined based on the following analytical method :

Friction force acting on an infinitely small area (fig.2) is : $ds = 2/\pi P \delta r$ ... (m^2)

$dF = \mu\, p(r).\, ds = p(r).\, 2\pi r\, dr\, \mu$ ....(N)

The moment of this force around the rotational axis is.

$dT = rdF = 2\pi p(r)\, \mu\, r^2 dr$ (N-m)

Therefore, heat generated in the area considered is.

$dq = dT, 2\pi n/60$ (N-m/sec) $= 1.04 * 10^{-4} dT.n$ (Kw)

Where dF = friction force on the elementary area considered.

dq = total power generated from elementary area.

n = speed (rpm). μ = co-efficient of friction.

p(r) = pressure at radius r

Therefore, when p(r) = p and r varies from o to R

Torque $T = 2/3/\pi\ p\mu\, R3 =$
$2.094\, \mu\, P\, r^3$ (N-m) ....(1)

and the corresponding power is given by.

$q = 1.04 * 10^{-4}\, T\, n$ ....(Kw)

On the basis of the above expressions, it can be concluded that for a given pair of surfaces intensity of heat liberation during friction welding is determined by the relative rotational speed, axial pressure and the size of the cross section of the weld pieces in contact. The friction coefficient is greatly dependent on process parameters such as surface finish, speed and unit load and it changes with duration/time.

The total power input may be assumed (Fig. 4) to consist of :

$q - wave + W\Delta\, e - \lambda t$

where Wave , WΔ and $e\lambda$ may be experimentally determined. The value of I varies from 5.5 x 10-4 Kw/mm^3. rev. to 7.2×10^{-4} Kw/mm^3 rev. under pressure p(r) between 70 N/cm^2 & 450 N/cm^2 and r.p.m. between 3000 & 350. for rods of diameters from 6 mm to 1.00 mm.

Temperature Characteristics : The governing differential equation for heat conduction in cylindrical co-ordinates (Fig.2) is given by :

$$\frac{\delta^2 T}{dr^2} + \frac{1}{r} + \frac{\delta T}{\delta r} + \frac{1}{r^2} + \frac{\delta^2 T}{\delta\theta^2} + \frac{\delta 2T}{\delta Z2} - \frac{1}{\alpha}\,\frac{\delta T}{\delta t} = -\frac{q}{K}$$

Assuming that the average cross-sectional temperature along face of the weld piece is same, then the equation (4) reduces to :

$$\frac{\delta^2 T}{\delta Z^2} - \frac{1}{a}\,\frac{\delta T}{\delta t} = \frac{q\delta}{k}$$

Where K = Coefficient of thermal conductivity, a = thermal diffusivity,

β = 1, when Z = L

= 0, when Z = L

the exponential energy input of equation (3) is substituted equation (5). The governing equation becomes.

$$\frac{\delta^2 T}{dZ^2} - \frac{1}{a}\,\frac{\delta T}{\delta t} = \frac{\beta}{k}$$

(Wave + WD e-It,)

This complex equation can be solved first by Laplace transformation and then by finite sine transformation. It is reported that for steels, the best upper limit of the interfacial temperature is170-200°c below the melting temperature. This temperature is attainable within 8 to 25 sec. under 70 to 450 N/cm2 heating pressure and 1.0 to 3.0 metre/sec. relative tip velocity.

The Forging upsetting phase : The forging phase follows the heating phase and shoftened plastic interfacial metal squeezes and expels out much of the trapped oxides, voids and contamination into flash. As a result of this clean pure surfaces is pushed into intimate contact for a resultant atomatic bonding. The rigid platen moves towards the interface. Fig 5 depicts a typical flash of two weld pieces. At the onset of forging the lines OA and OA lie within the abutting interface while elements AB and AB lie along the lateral surfaces of the rods. The curved profile of the AB and AB is the flash due to upsetting. About 80 to 95% of the original interfacial material of the plastic zone is generally forced into flash in order to have good quality welding. High strength alloys such as stainless steel and nickel base alloys require much higher forging pressure.

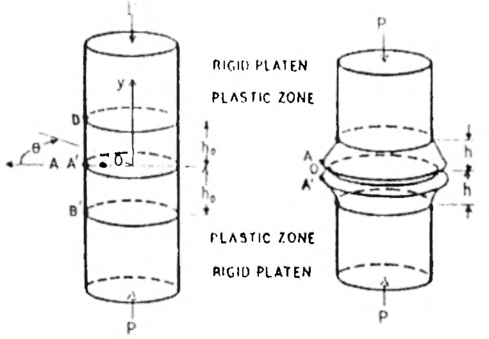

Fig 4 : Apprearence of Weld Piece During Forging

Estimated Parameters for Mild Steel joints

A comprehensive figure (data) depicting the ranges of drive power, friction force, forge force, r. p. m. etc. for various sizes of steel rod is estimated on the basis of the procedure mentioned in the analysis part pf this work and indicated in Table 1.

Sl. No.	Size (dia.,mm)	r.p.m. force in	Friction in sec KN (max) I	Duration force	Forgetion in secl n KN	Duration n kw (max)	Power (max)
1.	0.8 to 3.0	25000-6500	.005 .03	20 - 4.	0.6	2.0	0.1
2.	3.0 to 6.0	6500-3000	.02-.15	22 - 4	0.25	2.0	0.5
3.	6.0 to12.0	3000-1500	.07-0.5	30- 6	1.0	3.0	2.0
4.	12.o to 20.0	1500-1000	.2 -1.25	36 - 8	4.5	3.0	5.0
5.	12.0 to 25.0	1500-750	.3 - 2.0	40 - 8	8.0	4.0	10.0
6.	12.0 - 30.0	1500-750	0.4 - 3.0	40 - 10	11.0	4.0	12.5
7.	30.0 to 60.0	750-375	1.5 - 2.0	48-12	25.0	6.0	60.0
8.	60.0 to100.0	375-200	5 - 35	50-12	75.0	10.0	150.0

TABLE -1 Estimated data of friction heat, forge force, r. p. m., power requirement & duration for various sizes of mild steel rod.

DESIGN CONSIDERATION

Two varieties of Friction welding machines are available. Continuous Drive and Inertia Drive. In the Continuous drive, one work piece is rotated at constant speed and the other stationery piece rubs under pressure against it for some duration. The rotating piece is then stopped for subequent forged welding. In the Inertia welding, the rotary work piece receives energy from the flywheel of the system. The flywheel is accelerated to a particular speed to store some kinetic energy. The flywheel is then disengaged from the drive and the work pieces are brought together and kept under pressure. The flywheel energy is dissipated through the friction interface and its speed decreases with time. The forging force is then applied to the work pieces to consolidate the welding of the pieces

In this article, design consideration for the development of Continuous Drive Friction Welding Machine is attempted. The basic requirements for the design analysis are :

- Adequate rigidity of the load carrying component of the machine in order to :
  * facilitate rapid starting & instantaneous stopping of the machine under forging load.
  * impart force for a predetermined duration during heating and consolidation of welding.
- The main frame should be sturdy enough to absorb any shock or vibrations.

In order to accomplish aforementioned requirements the machine consists of two parts viz, stationary part and sliding part. The schematic of the stationery part is shown in fig.7. Its essential components are :

- Main shaft to carry belt pully for obtaining drive power, brake drum for stopping, clutch for transmitting power and set of bearings to withstand axial load under motion. The drive shaft is suitably fixed in a fixture.
- The design analysis of main shaft to house the clutch, break, chucks etc. and selection of bearings, collet chucks, clutch and breaks are very important and may be systematically carried out as follows :

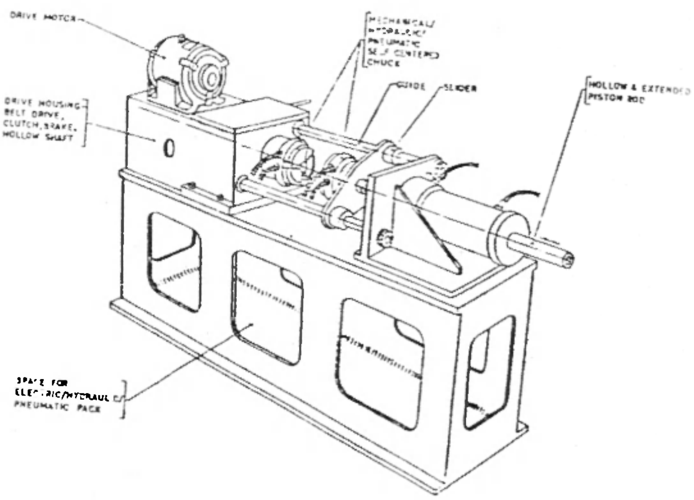

Fig 6 : Continuous drive friction welding machine – Schematic

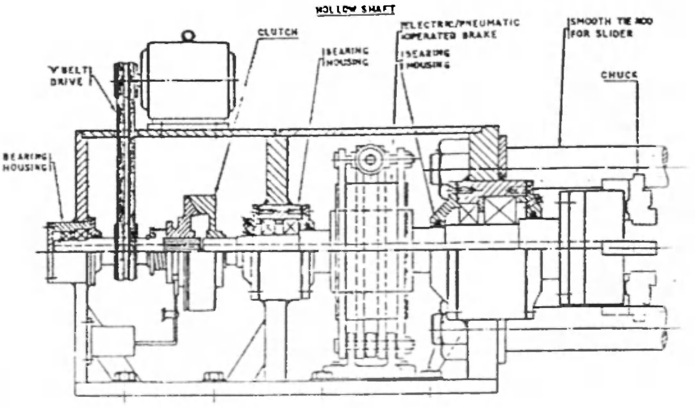

Fig 7 : Schematic of Drive Arrangement

Collet/ Self centering chuck : The parts to be welded are properly positioned and held firmly in the chucks so that, no slippage occurs during friction heating and forge welding, welded part is to be ejected from the machine chuck as quickly as possible in order to fix new parts to be welded. This feature decides productivity. Hand/manually operated chucks may be used to carry weld / forge load upto 0.5 K. N. Pneumatically operated chucks may be used to carry weld/forge load from 0.5 KN to 5.0 KN and hydraulically operated ones need to be incorporated for higher load beyond 5.0 KN. To accomodate longer work pieces / Jobs hollow chucks are to be used.

Bearing : Selection of bearing is very important as these are to carry the entire axial and radial loads during friction heating and forge welding phase under rotation. Combination of hydrodynamic air bearings and aerostatic thrust bearings capable of carrying thrust load of 0.1 K. N. at r.p.m. above 6500 may be used for work piece below 3.0 mm. Rolling contact bearings may be considered for r. p. m. below 6500 for thrust above 0.1 K. N. Either a set of self aligning ball bearings or set of double row angular contact ball bearings may be used to carry thrust load of 0.05 to 5 KN at r.p.m. between 1000 to 3000. Set of spherical roller bearings and roller bearings may be used to carry the thrust load between 0.5 KN to 1000 KN at r.p.m. between 250 to 3000.

Shaft : The design of shaft requires consideration of power and torque requirements which may be evaluated by analytical method and following standard norms of design.

Clutch & Brake : Brake and clutch need to be incorporated in the machine which is driven by an electric motor. Clutch is not to be used where drive is either an airturbine or a fractional horse power motor as inertia of these are negligible. Hydrostatic drive also does not require any clutch and brake. Clutch engages the rotating parts of the machine with drive during friction heating while break remains in released condition. The brake should be applied while clutch is in disengaged state in order to stop the rotating parts during consolidation period. Clutch needs to be disengaged before break is applied else there is chance of stalling of motor which may lead to motor/electrical failure. Disc type of brakes are used where there is space limitation and can be directly mounted on the free end side of the motor and should be used below 1.5 Kw. Shoe type brakes may be used for 1.5 to 5.0 Kw.

The **clutch** comprises of a powerful magnet with friction lining on one side and armature/friction disc on the other. Power is transmitted through lining & disc. A small air gap is maintained between the lining and disc faces. Magenetic field exerts necessary pressure pull between the friction lining and friction faces during energisation of its electrical field. The electromagnet is supplied from a d.c. supply source or a.c. supply through rectifier.

$$\text{Required Torque} = \frac{\text{Kw} \;.\; 9.54}{\text{r.p.m.}} = (\text{KN-m})$$

Recomended torque should be chosen as 1.5 times the average estimated load torque. Both clutch and brake may be either electrically or pneumatically or hydraulically operated depending upon the requirement of estimated intensity of pressure/load.

Sliding Parts : Sliding parts consist of chuck for holding the stationary work piece and actuating mechanism. Smooth and almost frictionless movement need to be accomplished by the sliding part. This sliding feature is an essential requirement for

- Fixing of the work pieces to be welded.
- Accomodating displacement during frictional heating and upsetting during forge welding.
- Facilitating quick withdrawl of product.

The smooth actuation of stationary part can only be achieved by suitably providing either smooth bush fixed on movable housing on a set of guide/tie rods fixed on stationary housing or on dovetail arrangement. The actuation of slider can be achieved by either providing double acting cylinder operated by pneumatic or hydraulic means for larger loads above 0.1 KN or mechanical means for lesser loads of 0.1 KN. To and fro motion at desired rate may be achieved by providing suitable circuit and they are shown in Fig. 8 & 9

Drive : The choice on the selection of drive requires the following consideration :

- Compressed air driven turbine motors are to be used for high speed above 6500 r.p.m. and low load applications below 0.1 Kw. D. C. motor to be used for speed between 3000 r.p.m. to 6500 r.p.m. and power upto 0.5 Kw. A. C. motor should be adopted for moderate speeds from 350 r.p.m. to 3000 r.p.m. and power upto 50 Kw.
- For low r.p.m. between 200 to 375 and high torque/power upto 250.0 Kw, hydrostatic drive needs to be incorporated. The schematic of air motor circuit and hydrostatic motor drive circuit are shown in Figs. 10 & 11.

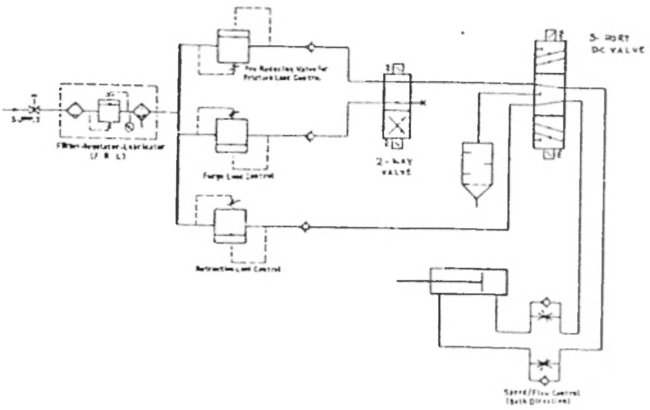

Fig 8 : Pneumatic cirucit for to and fro motion including supply of friction load and forge load

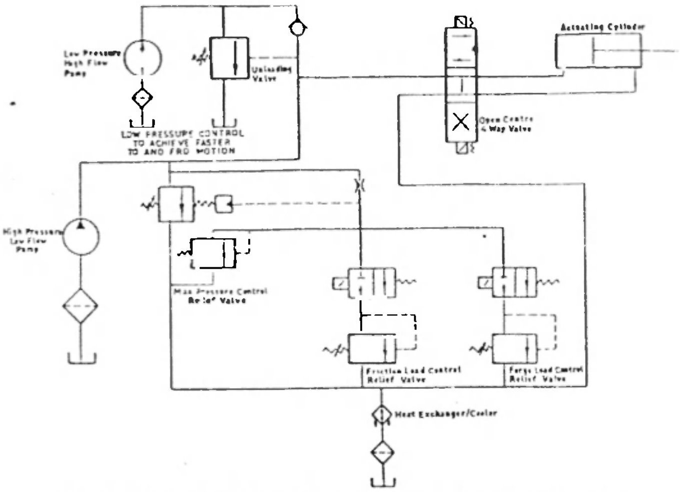

Fig 9 : Hydraulic Circuit for to and fro motion including the supply of friction and forge load

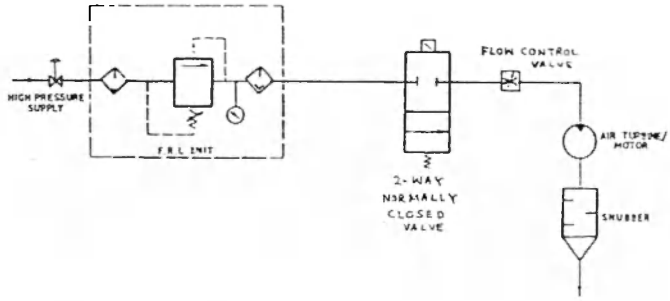

Fig 10 : Circuit for air turbine /Motor Drive

Welder : The main frame to house stationary parts, rotary parts may be fabricated or cast following standard norms. Heavy duty machines should be made from castings as they serve better in absorbing vibrations. Hollow shafts as well as piston rods needs to be considered for accomodating longer work pieces. The schemetic of standard welder is shown in Fig.6

CONCLUSION

A detailed design analysis of the continuous Drive F.W. machine based on considering the effect of peripheral speed, axial force during heating/forging phase and duration of each phase has been given in this manuscript. Table 1 indicates estimated data for mild steel rods. The analysis may be used for estimating data for continuous drive F. W. machines. Design analysis considered here are mainly for mild steel, alloy steel & similar metal joints. The materials for procurement of item such as bearing, hydraulic/pheumatic items, controller, chucks, drive systems are available in the country. In order to reduce the import bill, F.W. machines and valuable products can be easily made. This article may be treated as a useful guide.

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