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Research and Test of the Self-Designed and Manufactured Rotary Friction Welding Machine with CT3 Steel Samples

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Abstract. This paper presents the results of research and test of the self-designed and manufactured rotary friction welding machine. Tensile test results show that the tensile strength of the material after welding is satisfactory according to the standards of the material; the elongation is within the elongation limit of the welding specimen; the yield limit is greater than the minimum yield limit of the material. The parameters of the welding equipment are guaranteed according to the design requirements.

Introduction

Friction welding is the welding method with the most stable and durable welded joint structure compared with the method of fusion welding of the material. In addition to the outstanding advantage in terms of ensuring the mechanical properties of the welded joint, an advantage that other welding methods cannot do is to connect different materials through the process of friction, the materials are diffused into each other. With rotary friction welding, when two parts rotate relative to each other, generating frictional heat that melts the material at the contact area, the two parts are pressed together to create a welded joint [1-3], [14-18], Fig. 1.

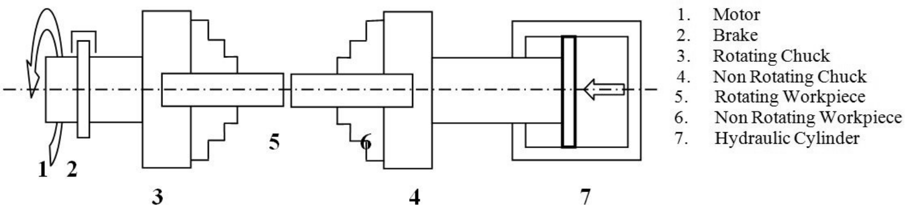


Fig. 1 Operating principle of rotary friction welding machine

In the 60s of the twentieth century, rotary friction welding developed strongly in the United States. Most of the equipment manufactured during this period was researched by AMF, Caterpillar, and Rockwell International companies [1-3]. Currently, rotary friction welding is strongly developed to meet the increasing needs of the manufacturing industry. At universities, a lot of research on rotary friction welding has been carried out in various aspects. Several in-depth studies on rotary friction have been carried out in the world. Researches on rotary friction welding machines: Gourav sardana and Ajay Lohan, have researched special fixture for friction welding on lathe machine [1]; Jagroop Singh, Karamdeep Singh, Department of Mechanical Engineering, ACEM, Kapur thala, Punjab, India have researched rotary friction welding on lathe machine with stailstock [2]; P. A. Thakare, Lt Randheer Singh designed and developed the micro rotary friction welding machine and investigated the friction welding parameters for similar materials [3]. Researches on welding of different materials includes: H. Ochi, working at Welding Research Center, Osaka Technical Research Institute, Japan, together with K. Ogawa studied the properties of the welds of aluminum alloy and steel. [27]; Z.Lindemann, K. Skalski, W. Wosin Ski, and J. Zimmerman studied the thermo-mechanical phenomenon in the process of friction welding of corundum ceramics and aluminium [14]; Eder Paduan Alves, Francisco Piorino Neto, Chen Ying An, Euclides Castorino da Silva conducted an experimental investigation of temperature during rotary friction welding of AA1050 aluminum with AISI 304 stainless steel [24]; M. B. Uday, M. N. Ahmad Fauzi, Zuhailawati H, A.B. Ismail of University of Materials and Mineral Resources Engineering, Malaysia, studied the effect of welding speed on the mechanical strength of friction welded joint of YSZ-Alumina composite and 6061 aluminum alloy [5]. Research on thermo-mechanical phenomena in the process of rotary friction welding includes authors with the following published work: Ruma Mohd Abdul Wahed, Mohammed Farhan studied the effect of external heating of the friction welded joint [17]; M. B. Uday, M. N. Ahmad Fauzi, Zuhailawati H, A.B. Ismail of University of Materials and Mineral Resources Engineering, Malaysia, studied the effect of welding speed on the mechanical strength of friction welded joint of YSZ-Alumina composite and 6061 aluminum alloy [5]. Jatinder Gill, Jagdev Singh experimentally studied the effect of heating time on the mechanical properties of nylon joints producced by friction welding [18]; Eder Paduan Alves, Chen Ying An conducted an experimental determination of temperature during rotary friction welding of dissimilar materials published in Scientific and Engineering Publishing Company [15]; Ali Moarrefzadeh studied the effect of heat in the friction welding process, published in Journal of Mechanical Engineering 2012 [16]. Evaluation of rotary friction welding includes the typical authors and works such as G.J. Baxter, M. Preuss and P.J. Withers at Manchester Institute of Natural Materials Research, UK, studied inertial friction welding of nickel base superalloys for aerospace applications [4]; Piaar Nagar, D. Ananthapadmanaban studied the friction weldability of low carbon steel with stainless steel and aluminum with copper [30]; P. Shiva Shankar, L. Suresh Kumar, N. Ravinder Reddy used Taguchi method to conduct an experimental investigation and analyze the friction welding parameters for Cu Zn28 copper alloy [6]; Amit Handa, Vikas Chawla made a review to evaluate friction welding [37]; Veerabhadrappa Algur1, Kabadi, Ganechari and Sharanabasappa conducted an experimental investigation on friction characteristics of modified ZA-27 alloy using taguchi technique [7]; Amit Handa Punjub, Vikas Chawla Dav conducted an experimental study on mechanical properties of friction welded AISI 1021 steels [8]; Mumin Sahin and Cenk Misirli studied the mechanical and metallurgical properties of Friction Welded Aluminium Joints [31]; Ali. Moarrefzadeh performed a Numerical Modeling of Friction Welding Process [38]; The research team of Baiju Sasidharan, Dr.K.P.Narayanan, R. Arivazhakan studied the influence of interface surface geometries in the tensile characteristics of friction welded joints from aluminium alloys [20, 32].

Friction welding is one of the environmentally friendly welding methods. The main source of welding energy is the heat source due to friction between the contacting surfaces of the welding parts. This heat source causes the surface of the part to flow intensely in the structure of the material, a new feature in current biomechanical engineering. The welding principle is completely new, so it needs a lot of research from basic to in-depth. The material organization at the welded joints changes compared to the original material, and nanostructures can be achieved, which is very significant in the new materials industry. The requirement for experimental equipment is simple, and the theoretical basis encapsulated in mechanical engineering, which is very suitable for current research conditions in universities.

Models of Rotary Friction Welding Machines Designed and Manufactured

Based on the reference to the studies [1-3], [6-8] and the actual working conditions of the research team, after analyzing the options, an operating principle of the rotary friction welding machine was selected as Fig. 1, 2D design model as Fig. 2. Main parameters typical for welding process include: spindle rotation speed, friction pressure and friction time, forging pressure and forging time, upset length.

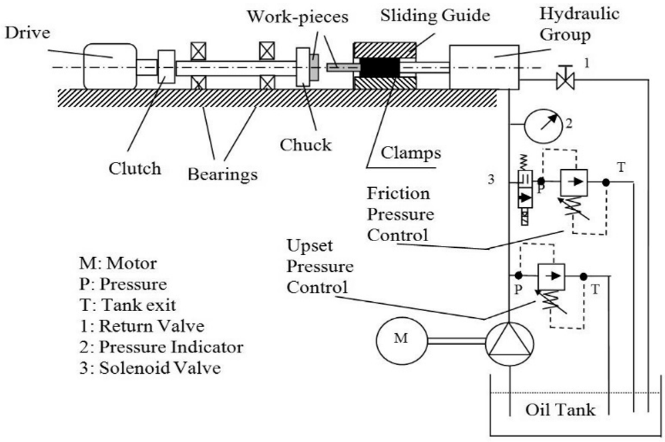
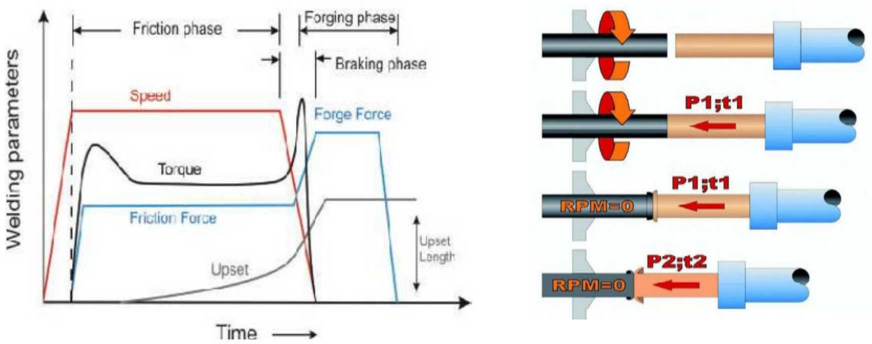


Fig. 2 2D design model of rotary friction welding machine

Fig. 2 and Fig. 3a show that when the rotation speed reaches a given speed n, hydraulic action causes two surfaces to rub against each other. Then the torque increases, and when the two frictional surfaces generate heat, the torque decreases. This stage is the friction phase. During the friction phase, the length of the workpiece is shortened by a small amount. When the friction surface has material overflow, the brake mechanism makes the rotation speed n stop suddenly. During breaking the torque is maximum and the torque is zero when the rotation speed n is zero. This is the braking phase. The braking phase takes place as quickly as possible (if the braking time is large, the heat reduction of the welded joint is limited). When the braking phase is about to end, the pressure should be increased so that the two surfaces diffuse intensely into each other. This stage is the forging phase. The steps to perform the rotary friction welding process are shown in Fig. 3b.



a) *b)*

Fig. 3 Parameters and phases of rotary friction welding process

The rotary friction welding machine is manufactured (Fig. 4) fitted with a solenoid valve to control the hydraulic system (principle shown in Fig. 2).

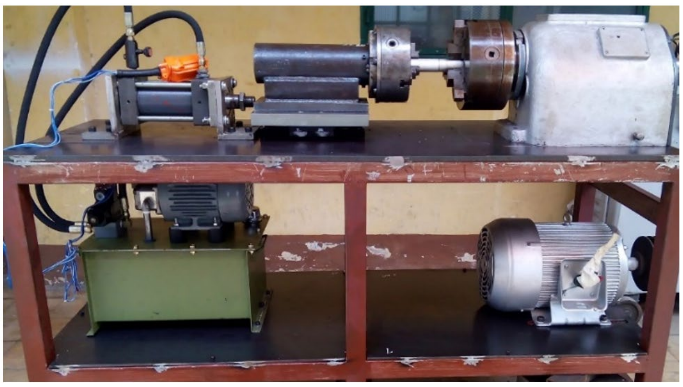


Fig. 4 The rotary friction welding machine is manufactured

Experiments

Sample for experiment. Test specimens of solid circular shape, with a diameter of 14 mm and a length of 100 mm, are made of CT3 steel with strength limits according to ГОСТ 380 - 89 standard as shown in Table 1.

Table 1. Mechanical properties of CT3 steel

Standard	Mechanical properties		
	Yield limit (N/mm2)	Tensile Strength (N/mm2)	Elongation (%)
ГОСТ 380 - 89	225 min	373 ÷ 461	22 min

Measuring instruments. In the study, the CHT4106 universal tensile strength testing machine was used to measure the mechanical properties of the samples after rotary friction welding.

Fig. 5 HT4106 model universal compression tensile machine

HT4106 model universal compression tensile machine with load force of 1000kN, can perform tensile, compression, bending and cutting tests. Test standards are in accordance with ISO, ASTM, etc. With PowerTest software of SANS, all data and management are in the database, easy to access and transfer to other softwares such as Excel. Parameters such as yield limit, strength limit, relative elongation, elastic modulus, etc. can be measured or calculated automatically. The machine also determines the bending resistance of metal and can display 3 curves at the same time: stress-deformation, force-time, force-elongation of the test specimen.

Experimental design. Test parameters include: rotation speed of workpiece, friction force, friction time, forging time, forging force, upset length. In which, there are 2 fixed parameters (rotation speed of workpiece n, upset length l), 2 variable parameters that can be controlled (axial pressure in the friction stage $P1$, axial pressure in the forging stage $P2$) and 2 calculated dependent parameters: friction time $t1$, forging time $t2$.

Table 2. Input parameters of the rotary friction welding test specimen

No	Axial pressure at stages	Symbol		Design variable value			Unit
		Nature	Encode	(-1)	(0)	$(+1)$	
1	*Friction*	$\boldsymbol{P1}$	A	50	70	90	N/mm^2
2	*Forging*	$\boldsymbol{P2}$	B	110	130	150	N/mm^2

The second-order symmetric mixed quadratic experimental planning of the form B with the polynomial regression equation has the general form as formula (1):

$$y = b_o + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 \sum_{\substack{i<j \\ i,j=1}}^{k} b_{ij} x_i x_j \quad (1)$$

The study has chosen the second-order symmetric mixed planning of the form B, the experiment at the center of 2 to help keep the number of experiments to a minimum. Natural form planning matrix is shown in Table 3.

Table 3. Experimental planning matrix with input parameters

Test specimen	n (rpm)	**Axial pressing force**		**Time**		l (mm)
		$P1$ (N/mm^2)	$P2$ (N/mm^2)	$t1$ (s)	$t2$ (s)	
1	1.450	50	110	50	7	4
2	1.450	90	110	36	7	4
3	1.450	50	150	50	5	4
4	1.450	90	150	36	5	4
5	1.450	50	130	50	6	4
6	1.450	90	130	36	6	4
7	1.450	70	110	43	7	4
8	1.450	70	150	43	5	4
9	1.450	70	130	43	6	4
10	1.450	70	130	43	6	4

Conducting experiments. The samples are cut to length and cleaned to remove oil, grease, etc. and ensure a flat, smooth, swarf-free work surface so that the two surfaces are in even contact, good friction, and faster heating time. 10 experiments with the same parameters are carried out as shown in Table 3 according to the basic stages: Friction process (Fig. 6) and Forging process (Fig. 7).

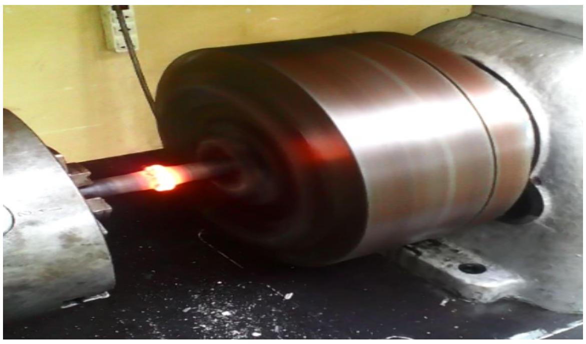


Fig. 6 Friction process

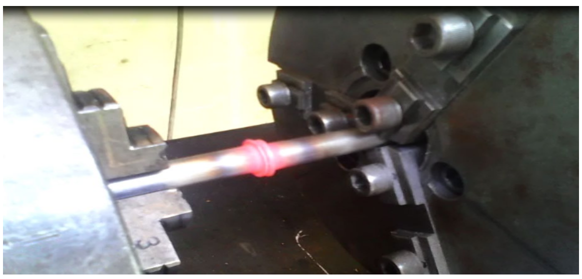


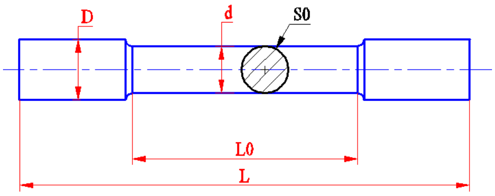
Fig. 7 Forging process (upset)

Results and Discussion

After the rotary friction welding equipment is manufactured and the above samples are tested, it shows that the friction welding equipment gets the set requirements: high rigidity, low vibration during operation, the main shaft motor ensuring the operating capacity and reaching the number of revolutions according to the design requirements, the sliding table mechanism operating smoothly and ensuring stability during the welding process, the hydraulic system ensuring the original design pressure.

According to the ASTM E8 standard, the samples after rotary friction welding (Fig. 8) are machined by turning method before the tensile test (Fig. 9). The sample after tensile test to determine mechanical properties is shown in Fig.10.

Fig. 8 CT3 steel welding product



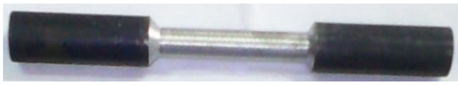


Fig. 9 Tensile test specimen according to ASTM E8 standard

Fig. 10 Sample after tensile test

The number of repeated experiments of the planning was calculated and selected as 3. CHT4106 devices were used to measure the strength limit, yield limit and calculate the relative elongation with the results table as shown in Table 4.

Table 4. Tensile test results

Test specimen	**Tensile strength, $\overline{\sigma_b}$** (N/mm^2)	**Elongation, $\overline{\delta}$** (%)	**Yield limit, $\overline{\sigma_{0.2}}$** (N/mm^2)
1	401,7	16,7	281,6
2	401,7	17,2	281,6
3	403,7	17,1	284,2
4	407,9	17,8	286,6
5	403,5	16,9	283,7
6	407,2	17,5	284,2
7	406,7	16,9	281,8
8	405,6	16,8	282,5
9	404,7	16,3	281,2
10	404,2	16,5	281,7

The relative elongation after break is calculated by the formula: $A = \left(\frac{L_u - L_0}{L_0}\right).100$

The relative contractility is calculated by the formula: $Z = \left(\frac{S_0 - S_u}{S_0}\right).100$

In which:

L_0: Initial session length.
L_u: Session length at the end
L: Total length of the original sample.

L_c: Sample length at the end.
S_0: Original cross-sectional area of the parallel section.
L_u: Minimum cross-sectional area after cutting.

Tensile strength σ_b. Synthesis and analysis of parameters affecting tensile strength are shown in Table 5.

Table 5. Parameters affecting tensile strength

Term	Coef	SE Coef	T-Value	P-Value
Constant	405.150	0.161	2511.87	0.000
P1	1.061	0.132	8.06	0.000
P2	0.867	0.132	6.58	0.000
P1*P1	-1.189	0.208	-5.71	0.000
P1*P2	0.692	0.161	4.29	0.000

The regression equation characterizing for the malfunction of the axial pressing force of friction and forging parts when welding friction can only be natural as follows:

$$\sigma\_b = 396.97 + 0.2444\ P1 - 0.0777\ P2 - 0.002972\ P1*P1 + 0.001729\ P1*P2 \quad (2)$$

From here, graphs are built to show the influence of 2 input parameters on the tensile strength of the sample as shown in Fig. 11.

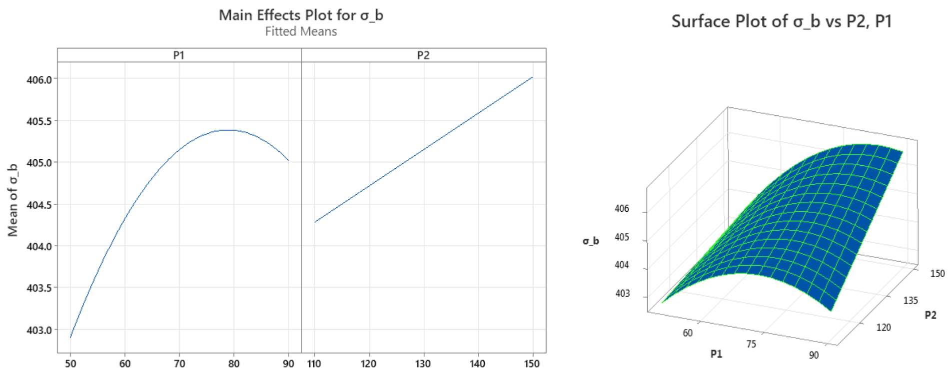


Fig. 11 Tensile strength analysis results

From the results of the analysis we realize that the higher the friction, the higher the strength, and when the maximum value is reached, it decreases. As the forging element increases, the tensile strength of the detail will increase steadily.

Elongation δ. Synthesis and analysis of parameters affecting elongation are shown in Table 6.

Table 6. Parameters affecting elongation

Term	Coef	SE Coef	T-Value	P-Value
Constant	16.6024	0.0548	303.02	0.000
P1	0.3222	0.0374	8.61	0.000
P2	0.1500	0.0374	4.01	0.000
P1*P1	0.4119	0.0600	6.86	0.000
P2*P2	0.1619	0.0600	2.70	0.012

The regression equation characterizing the influence of axial pressure of friction and forging parts when welding friction to the elongation of the sample of the natural form is as follows:

$$\delta = 26.39 - 0.1281\,P1 - 0.0977\,P2 + 0.001030\,P1*P1 + 0.000405\,P2*P2 \quad (3)$$

From here, graphs are built to showthe influence of 2 input parameters on the elongation of the sample as shown in Fig 12.

From the results of the analysis, it is noticed that the higher the friction, the longer the elongation will decrease to the point of urination will increase. As the Forging factor increases, the elongation of the parts tends to increase but will initially decrease when it comes to the pole, which will gradually increase.

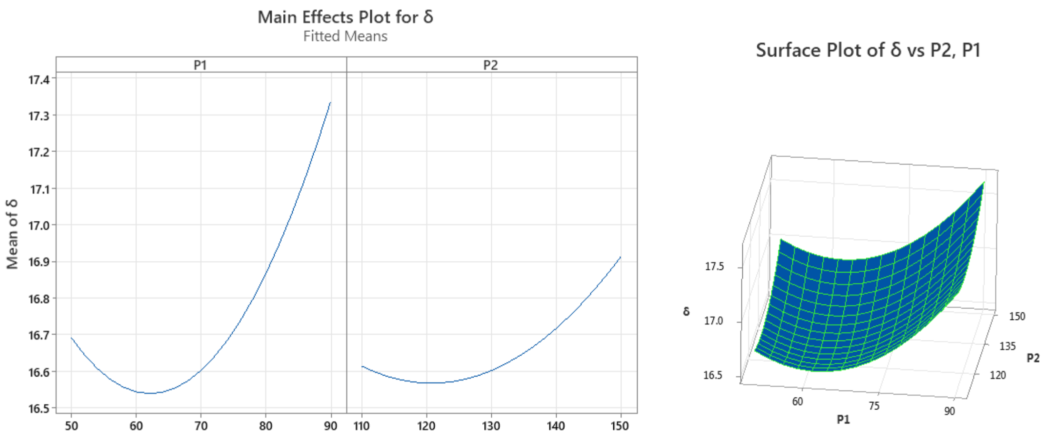


Fig. 12 Elongation analysis results

Yield limit analysis $\sigma_{0.2}$. Synthesis and analysis of parameters affecting yield limit analysis are shown in table 13.

Table 7. Parameters affecting the yield limit

Term	Coef	SE Coef	T-Value	P-Value
Constant	281.558	0.083	3407.21	0.000
P1	0.6111	0.0675	9.06	0.000
P2	1.3500	0.0675	20.01	0.000
P1*P1	1.942	0.107	18.20	0.000
P1*P2	0.2667	0.0826	3.23	0.003

The regression equation characterizing for the influence of axial pressing force of friction and forging parts when friction welding arrives yield limit analysis samples of natural form is as follows:

$$\sigma\_0.2 = 300.50 - 0.7357\,P1 + 0.0208\,P2 + 0.004854\,P1*P1 + 0.000667\,P1*P2 \quad (4)$$

From here, graphs are built to show the influence of 2 input parameters on yield limit analysis of the sample as shown in Fig. 13.

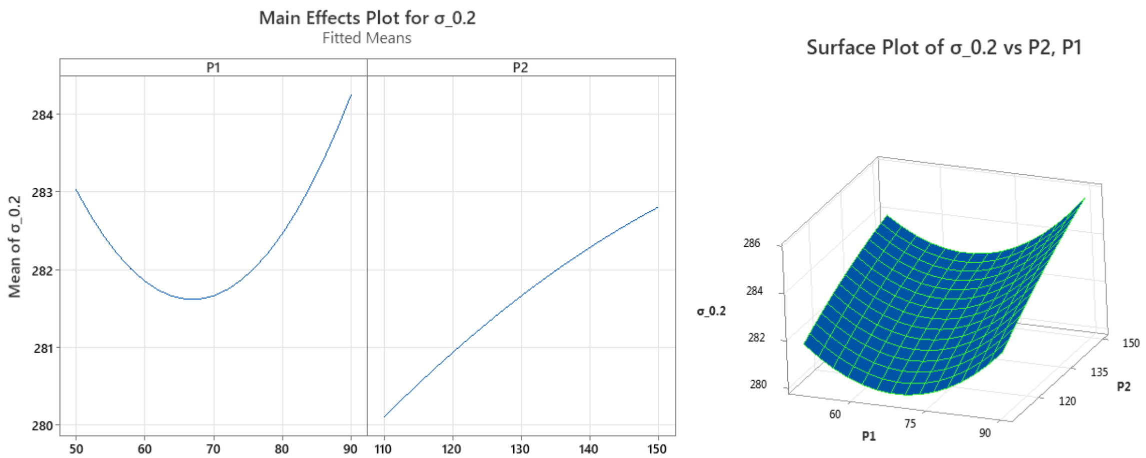


Fig. 13 Analysis results yield limit analysis

From the chart, it is noticed that the higher the friction, the lower yield limit. Especially, when it decreases to the minimized value, it tends to increase again. The more the forging factor increases, the yield limit increases.

Tensile test results with mechanical properties are synthesized and compared with the mechanical properties of the sample material (Table 1), with the table as shown inTable 8.

Table 8. Table comparing the properties of the welding specimen with that of the material

Tensile strength (N/mm^2)		**Elongation** (%)		**Yield limit** (N/mm^2)	
Standard	Experiment	Standard	Experiment	Standard	Experiment
373 ÷ 461	401.7÷407.9	22 min	16.3÷17.8	225 min	281.2÷286.6

Conclusion

The rotary friction welding machine has been successfully researched and manufactured, put to the test and achieved good results. The rotation speed of the part is stable and ensures the maximum number of revolutions required for friction welding is 1450 rpm. The hydraulic cylinder's propulsion mechanism is stable and generates pressure in accordance with the requirements of each material (160Mpa). The structure of the welding machine is firm, ensuring stability during operation. Transmission sliding table mechanism is smooth and stable. Materials with the same properties can be welded, meeting the set requirements.

References

[1] Gourav sardana, Ajay Lohan, Friction Welding on Lathe Machine with special Fixture, International Journal of Innovations in Engineering and Technology (IJIET) Vol. 2 Issue 3 June 2013.

[2] Jagroop Singh, Karamdeep Singh, Fabrication of Friction Welding on Centre Lathe: A Case Study, IJIET Vol. 4, IssuE2, May- ocTobER2014.

[3] P A Thakare, Lt Randheer Singh, Design and Development of Micro Friction Welding Machine and Investigation of Welding Parameters for Similar Materials, International Journal of Scientific & Engineering Research, Volume 5, Issue 6, June-2014.

[4] Ahmet CAN, G.J. Baxter, M. Preuss and P.J, Research on the inertia friction welding of nickel base superalloys for aerospace applications studied by G.J. Baxter, M. Preuss and P.J. Withers at Manchester Institute of Natural Materials Research, UK;

[5] M. B. Uday, M.N. Ahmad Fauzi, Zuhailawati H., A.B. Ismail, Effect of welding speed on mechanical strength of friction welded joint of YSZ-Alumina composite and 6061 Aluminum Alloy, Materials Science and Engineering A 528 (2011) 4753–4760

[6] P. Shiva Shankar, L. Suresh Kumar, N. Ravinder Reddy, Experimental investigation and stastical analysis of the friction welding parameters for the copper alloy - cu zn28 using taguchi method, International Journal of Research in Engineering and Technology, eISSN: 2319-1163 pISSN: 2321-7308.

[7] Veerabhadrappa Algur1, Kabadi, Ganechari and Sharanabasappa, Experimental investigation on friction characteristics of modified ZA-27 alloy using taguchi technique, IJMERR, Vol. 3, No. 4, October 2014.

[8] Amit Handa punjub, Vikas Chawla Dav, Experimenttal study of mechanical properties of friction welded AISI 1021 steels, Sadhana, Vol. 38, Part 6, December 2013, pp. 1407–1419. © Indian Academy of Sciences.

[9] A. Kurt, I. Uygur, and U. Paylasan, Effect of Friction Welding Parameters on Mechanical and Microstructural Properties of Dissimilar AISI 1010-ASTM B22 Joints, 104-S, May 2011, vol. 90.

[10] P. Shiva Shankar, L. Suresh Kumar, N. Ravinder Reddy, Experimental investigation and stastical analysis of the friction welding parameters for the copper alloy – cu zn28 using taguchi method, International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308.

[11] P Sathiya, S Aravindan, A Noorul haq, K panneerselvam, Optimization of friction welding parameters using simulated annealing, IJEMS, Vol.13, February 2006, pp. 37-44.

[12] Sirajuddin Elyas Khany, K.N.Krishnan, Mohd Abdul Wahed, Study of Transient Temperature Distribution in a Friction Welding Process and its effects on its Joints, International Journal Of Computational Engineering Research (ijceronline.com) Vol. 2 Issue. 5.

[13] Prashant Rashmikant Pandya, Prof. Amol Bagesar, Prof. Jignesh Patel, Effect Of Welding Parameters On Burn-Off Length For Friction Welding Of Inconel 718 And SS 304 For Production Of Bimetal Poppet Exhaust Valve, IJSRD - International Journal for Scientific Research & Development| Vol. 2, Issue 04, 2014

[14] Z. Z. Lindemann, K. Skalski, W. Włosinski, and J. Zimmerman, Thermo-mechanical phenomena in The Process of Friction Welding of Corundum Ceramics and Aluminium, Bulletin of The Polish Academy of Sciences Technical Sciences Vol. 54, No. 1, 2006.

[15] Eder Paduan Alves, Chen Ying An, Francisco Piorino Neto, Eduardo dos Ferro Santos, Experimental Determination of Temperature during Rotary Friction Welding of Dissimilar Materials, 2012 Science and Engineering Publishing Company.

[16] Ali. Moarrefzadeh, Study of Heat Affected Zone (HAZ) in Friction Welding Process, Vol. 2 Issue. 5. journal of mechanical engineering vol. 1, no. 1, january 2012.

[17] Ruma Mohd Abdul Wahed, Mohammed Farhan, A Study on the Effect of External Heating of the Friction Welded Joint, International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 5, May 2013.

[18] Jatinder Gill, Jagdev Singh, Experimental study on the effect of heating time on mechanical properties of nylon-6 joints produced by friction welding, International Journal of Advanced Engineering Research and Studies E-ISSN 2249–8974.

[19] Ahmet Can, Mümin Şahin, Mahmut Küçük, Modelling of friction welding, international scientific conference 19 – 20 november 2010, gabrovo.

[20] Baiju Sasidharan, Dr.K.P.Narayanan, R.Arivazhakan, Influence of Interface Surface Geometries In The Tensile Characteristics Of Friction Welded Joints From Aluminium Alloys, International Journal of Innovative Research in Science, Engineering and Technology An ISO 3297: 2007 Certified Organization, Volume 2, Special Issue 1, December 2013.

[21] Eder Paduan Alves, Chen Ying An, Francisco Piorino Neto, Eduardo Ferro dos Santos, Experimental Determination of Temperature during Rotary Friction Welding of Dissimilar Materials, Frontiers in Aerospace Engineering Vol. 1 Iss. 1, November 2012.

[22] Jatinder Gill, Jagdev Singh, Experimental study on the effect of heating

[23] time on mechanical properties of nylon-6 joints produced by friction welding, International Journal of Advanced Engineering Research and Studies E-ISSN2249–8974.

[24] Eder Paduan Alves, Francisco Piorino Neto, Chen Ying An, Euclides Castorino da Silva, Experimental Determination of Temperature During Rotary Friction Welding of AA1050 Aluminum with AISI 304 Stainless Steel, Vol 4, No 1, pp.61-67, Jan, Mar, 2012.

[25] Sirajuddin Elyas Khany, K.N.Krishnan, Mohd Abdul Wahed, Study of Transient Temperature Distribution in a Friction Welding Process and its effects on its Joints, International Journal Of Computational Engineering Research (ijceronline.com) Vol. 2 Issue. 5.

[26] Ruma, Mohd Abdul Wahed, Mohammed farhan, A Study on the Effect of External Heating of the Friction Welded Joint, International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 5, May 2013.

[27] H. Ochi, K. Ogawa, Friction Welding of Aluminum Alloy and Steel, International Journal of Offshore and Polar Engineering Vol. 8, No. 2, June 1998 (ISSN 1053-5381).

[28] Mümin ŞAHİN, Friction welding of different materials, international scientific conference 19 – 20 november 2010, gabrovo.

[29] P. Rombaut, W. De Waele and K. Faes, Friction welding of steel to ceramic, Sustainable Construction and Design 2011.

[30] Piaar Nagar, Chennai – 119, D. Ananthapadmanaban, Studies on friction weldability of low Carbon Steel with Stainless Steel and Aluminium with Copper.

[31] Mumin Sahin and Cenk Misirli, Mechanical and Metalurgical Properties of Friction Welded Aluminium Joints, 24 trang.

[32] Baiju Sasidharan, Dr.K.P.Narayanan, R.Arivazhakan, Influence of Interface Surface Geometries In The Tensile Characteristics Of Friction Welded Joints From Aluminium Alloys, International Journal of Innovative Research in Science, Engineering and Technology An ISO 3297: 2007 Certified Organization, Volume 2, Special Issue 1, December 2013.

[33] Song Yu-lai, Liu Yao-hui, Zhu Xian-yong, Yu Si-rong, Zhang Ying-bo, Strength distribution at interface of rotary-friction-welded aluminum to nodular cast iron, Transactions of Nonferrous Metals Society of China 18 (2008) 14 -18.

[34] K. Boonseng, S. Chainarong, C. Meengam, Microstructure and Mechanical Properties of Friction Welding in SSM356 Aluminium Alloys, International Journal of Emerging Trends in Engineering Research, Volume 2, No.4, April 2014.

[35] G.P.Rajamani,M .S.Shunmuga Man DK.P.Rao, Parameter Optimization and Properties of Friction Welded Quenched and Tempered Steel, 226-S, I June 1992.

[36] Jay Prakash Gavade, R.D. Rajopadhye, N.D.Jadhav, Dr. Prakash Ramdasi, A review on effects of processing parameters on mechanical behavior of different metals joined by continuous drive friction welding, IJESR/April 2013/ Vol-3/Issue-4/2777-2784, ISSN 2277-2685.

[37] Amit Handa, Vikas Chawla, Friction Welding - A Review, http://asianonlinejournals.com/index.php/Mare, Vol. 1, No. 2, 34-38, 2014.

[38] Ali. Moarrefzadeh, Numerical Modeling of Friction Welding Process, international journal of multidisciplinary sciences and engineering, vol. 2, no. 8, november 2011.

[39] Dr K. Narasimha Murthy, Dr V.P. Raghupathy, Mr D. Sethuram, Two Day workshop on Friction Welding & Friction Stir Welding 24 & 25 November, 2011, International Center for Advancement of Manufacturing Technology.