INFLUENCE OF PROCESS PARAMETERS ON HARDNESS AND MICROSTRUCTURE OF PRE-HEAT TREATED FRICTION WELDED 15CDV6 ALLOY STEEL

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Abstract— Friction welding is a relatively new joining process it is a solid state joining process the joints are formed by utilizing the heat generated by friction. This paper discusses the importance of hardness in friction welded components with respect to the process parameters. The process parameters considered in this research work are friction force, Forge force, rotational speed and burn-off length for the 15CDV6 alloy steel rods of 17mm diameter with an aim to understand the influence of process parameters on welds hardness properties and the microstructure is optimized to establish the weld quality using the Taguchi experiment design technique with an orthogonal array of $L_{9,}$ ANOVA. The various applications of the 15CDV6 alloy steel is mentioned in this paper the durability of the joint plays a major role to serve its purpose. The optimization of parameters of hardness will be useful for the joints of this particular 17mm diameter rods.

Keywords— Friction welding, 15CDV6 alloy steel, hardness, Taguchi method, microstructure.

I. INTRODUCTION

Friction welding is one of the solid state joining process by which the quality welded products can be produced, this method of joining has gained more importance in the fabrication industry. In the field of welding, the weld quality mainly depends on the type of welding, mechanical properties of the weld metal and heat affected zone (HAZ) which in turn is influenced by metallurgical characteristics and chemical compositions of the weld [1,2]. The advantages of this friction welding process include high reproducibility, less production time and low energy input. In this method the joints are formed by heat generated due to friction. The friction is achieved in this process by rotating one component at high revolutions per minute (rpm) in contact with a stationary component by applying axial pressure during rotation the temperature at the interface is increased until material reach the plastic state.

The heat in friction welding is generated by conversion of mechanical energy into thermal energy at the interface of work pieces during rotation under pressure [3, 4]. The simple set up of the friction welding machine is shown in Figure1. At a precise moment, the rotation is stopped and axial forging force is then applied between the two components [5]. Friction welding consistently provides high-strength, defect free joints and high productivity because of these advantages this welding technique has become the important for the manufacture of some automobile components, cutting tools such as drills, reamers and milling cutters, and pump shafts and also in the industries like aeronautical engineering, automobile engineering, submarine industry and heavy industry. Friction welding consists the parameters such as friction force, friction time, forge force (upset force), upset time, temperature measurement, burn off length, and rotational speed are the most important parameters, in this welding process the quality and strength of the welds depend on the proper selection of these parameters, these parameters that influence the weld quality, strength of the joint and the hardness of the heat affected zone(HAZ) [6,7].

In this study for the material 15CDV6 alloy steel the parameters friction force, forge force, rotational speed and burn off length were considered to optimize the mechanical properties for good quality of welds. The typical applications of 15CDV6 alloy steel material includes roll cages, rocket motor casings, track and push rods, uprights, pressure vessels, sub frames, wish bones, suspension components, and motor sport applications. The literature on this material research work is very scare, the components made up of this material should be hard and also to withstand the shock loads[8], therefore hardness properties of the joint is also necessary in the above field of applications, because of its importance this material is chosen for my research work as similar materials friction welded joints, joints of similar and dissimilar combinations are employed in different applications requiring various mechanical properties like hardness, tensile strength, brittleness, malleability etc and also to save cost incurred towards scared materials [9].

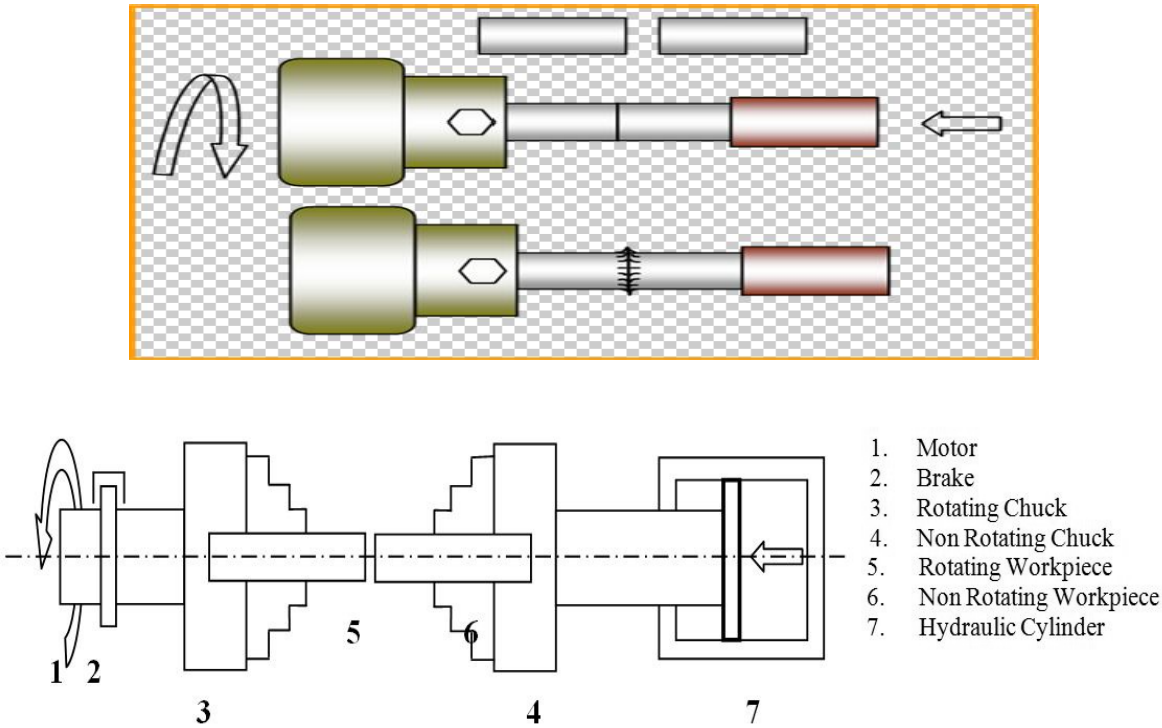


Figure1: Continuous drive Friction Welding machine setup

The Friction welding process can be divided into three different stages, stage I-III. [10]

Stage I: Is the friction stage at this stage wear and seizure occurs due to the combined effect of coulomb friction and sticking force this causes the rapid rise of interface temperature as a result the yield strength decreases, for good weld the temperature rise at the interface should be sufficiently high above (400^{o}C) this ensures adequate plastic deformation. Towards the end of this stage a large amount flash flow occurs, the friction force and spindle speed plays important role in rising the temperature at the interface.

Stage II: Adiabatic heating due to plastic deformation helps in retaining the interface temperature due to the setting of the dynamic balance between heat generation and heat conduction, and the plastic deformation occurs continuously at constant rate with the influence of friction force. This stage is dependent on the burn off length, and its duration is larger with the larger burn off length.

Stage III: In this stage the parts are suddenly brought to rest and a forge force is applied. The forge force is always higher than the friction force, sound joints are achieved in this stage. The axial reduction depends not only on the magnitude of forge force but also on the duration of the burn off length in stage II.

II. EXPERIMENTAL WORK

The material 15CDV6 alloy steel round rods of length 60mm and diameter 17mm were machined out from 20mm thick plates and these round rods are pre-heat treated for hardening to a temperature then allowed for cooling for tempering shown in table 1.The pre-heat treatment process of hardening develops the high hardness, wear resistance, strength and toughness in the material, but also at the same time this process makes the material ductile, to remove this ductility a further heat treatment process is applied which is called tempering.

This heat treatment process makes the steel as an important structural product[8] the joining of similar materials is made on friction welding machine. The chemical composition and mechanical properties of the base material is shown in table 2 and table 3.

Table 1: Heat treatment table

Process	Temperature (^{0}C)	Type of cooling	Time (Min)
Hardening	975	Forced fan air cooling	30
Tempering	650	Forced fan air cooling	60

Table 2: Chemical composition of the 15CDV6 Alloy Steel

Element	C	Si	Mn	S	P	Cr	M_0	V
Maximum	0.18	0.20	1.10	0.015	0.020	1.50	1.00	0.30

Table 3: Mechanical properties of the 15CDV6 Alloy Steel

condition	0.2% proof stress	Tensile strength	Elongation	hardness
1.7734.2 (annealed)	-	-	-	197HB
1.7734.4	550 mp_a min	700 mp_a min	13% min	-
1.7734.5	790 mp_a min	980-1180 mp_a min	11% min	-
1.7734.6	930 mp_a min	1080-1250 mp_a min	10% min	-

Figure 2: 15CDV6 alloy steel welded joints

In friction welding, generally surface preparation is not considered as a major requirement as surface irregularities are removed by scoring action and the debris get removed in flash. However Yilbas [11] and Hasui and Matsui [12] showed the surface preparation can significantly affect the joint strength. In this work, the contact surfaces of the round rods were machined before welding to produce smooth as well as oxide-free surfaces this also ensures perpendicularity which is also important for achieving sound weld joints.

The process parameters mainly considered in this current work are friction force, forge force, rotational speed, and burn off length, a Taguchi L_9 Orthogonal array was selected for the investigation of the effects of process parameters. The parameters design of Taguchi method provides a simple, systematic and efficient methodology for process parameters optimization [13], based on preliminary welding trials, three levels were considered for each of the process parameters. The working range of each parameter was decided upon by inspecting microstructure (cross section of a weld region for a smooth appearance without any visible defects [14]. The details of process parameters and their levels are shown below in Table 4.

Table 4: Process parameters and their levels.

Parameters (Factors)		level 1	level 2	level 3
Friction force (kN),	A	5	10	15
Forge force (kN),	B	15	25	45
Rotational speed (rpm),	C	1000	1500	2000
Burn off (mm),	D	2	4	6

The friction welding experiments were conducted as per the table 5, taking hardness of the joint as the response parameter in a randomized order using a fully automatic continuous drive friction welding machine made by ETA-Technology Bangalore at Defence Metallurgical Research Laboratory (DMRL) Hyderabad for each combination of process parameters two trial runs were made, equal length of similar round rods were employed on both rotating side (RS) and stationary side (SS) in all the cases.

The welded joints were made as standard specimens to the specifications and then the hardness tests were performed to the prepared specimens on Vickers hardness testing machine made by Matsuzs company with a capacity of 100gm to 1kg at Defence Metallurgical Research Laboratory Hyderabad, later on those samples were prepared for micro structural examination as per standard metallographic procedures and the resulting macro and micro structures are shown in figure 5, and figure 6.

Table 5: S/N Ratio of Hardness from Mid-Center

	PARAMETERS								
EXPT	A	B	C	D	TRIAL 1	TRIAL 2	TOTAL	AVG	S/N RATIO
1	5	15	1000	2	401	400	801	400.5	52.05205
2	5	25	1500	4	355	360	715	357.5	51.065521
3	5	45	2000	6	342	340	682	341	50.655088
4	10	15	1500	6	347	346	693	346.5	50.794065
5	10	25	2000	2	405	400	805	402.5	52.095318
6	10	45	1000	4	377	375	752	376	51.503757
7	15	15	2000	4	381	380	761	380.5	51.607093
8	15	25	1000	6	382	381	763	381.5	51.629891
9	15	45	1500	2	360	362	722	361	51.150144
					T=	6694		ΣY=	462.55293
								MEAN Y=	51.39477

Table 6: Mean response table of hardness from Mid-Centre

	Factor A	Factor B	Factor C	Factor D
Level 1	51.25755	51.4844	51.72857	51.765837
Level 2	51.46483	51.5893	51.00324	51.392124
Level 3	51.462376	51.1029	51.452499	51.026348
Difference	0.20728	0.4864	0.72533	0.739489
Rank	4	3	2	1

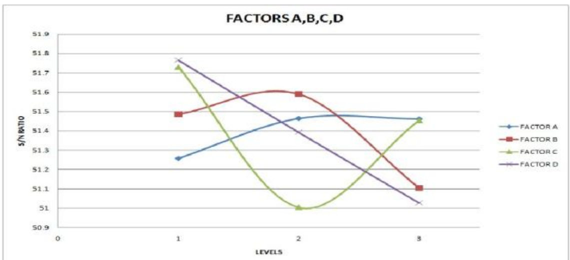


Fig3: Graphs of hardness of 15CDV6 alloy steel from Mid-Centre

Table7: ANOVA summary Table from mid-Centre

Process parameter	DOF	Sum of squares(SS)	Mean sum of square(MSS)	F-ratio	Percentage contribution
A	(2)	(279.11)	139.556	8.457912	Pooled
B	2	1484.1	742.056	44.973064	19.1257
C	2	2952.4	1476.22	89.4680135	38.0481
D	2	3011.1	1505.56	91.24579	38.8041
Error	2	33	16.5		4.02217
Total	8	7759.8			100.00

Table8: S/N Ratio of Hardness from centre

	PARAMETERS				TRIAL	TRIAL			S/N
EXPT	A	B	C	D	1	2	TOTAL	AVG	RATIO
1	5	15	1000	2	401	400	801	400.5	52.05205
2	5	25	1500	4	368	365	733	366.5	51.28148
3	5	45	2000	6	343	341	684	342	50.680522
4	10	15	1500	6	374	372	746	373	51.434177
5	10	25	2000	2	404	400	804	402	52.084521
6	10	45	1000	4	399	399	798	399	52.019458
7	15	15	2000	4	363	365	728	364	51.222028
8	15	25	1000	6	395	389	784	392	51.865721
9	15	45	1500	2	391	392	783	391.5	51.854635
					T=	6861		ΣY=	464.49459
								MEAN Y=	51.61051

Table 9: Mean response table from centre

	Factor A	Factor B	Factor C	Factor D
Level 1	51.338017	51.569418	51.97908	51.997069
Level 2	51.846052	51.529343	51.523431	51.507655
Level 3	51.647461	51.518205	51.329024	51.326807
Difference	0.508035	0.51213	0.65005	0.670262
Rank	4	3	2	1

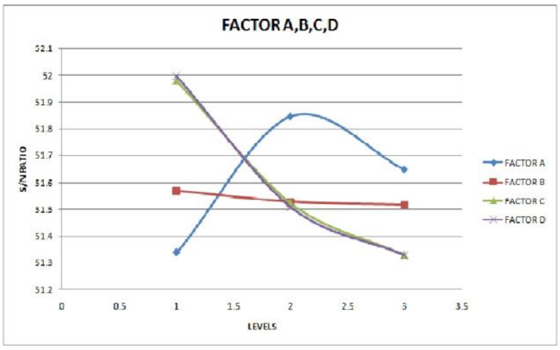


Fig 4: Graphs of hardness of 15CDV6 alloy steel from Centre

The graphs shown in the above figure 4, the S/N ratio value of factor A is high for level 2 but according to the value of its F-ratio it is pooled because of its poor significance as shown in table 7, and as the factor B has low significance where as the factors C and D the S/N ration value is high at level 1.

Table 10: Annova analysis for hardness from centre.

Process parameter	DOF	Sum of squares(SS)	Mean sum of square(MSS)	F ratio	Percentage contribution
A	2	1424	712.17	37.9822	20.469
B	(2)	297.3	148.67	7.9288	pooled
C	2	2480	1240.2	66.1422	35.6447
D	2	2719	1359.5	72.5066	39.0745
Error	2	37.5	18.75		4.81186
Total	8	6959			100.00

III. RESULTS AND DISCUSSION

3.1 PROCESS PARAMETER OPTIMIZATION

3.1.2 Hardness

The hardness test results on the welds made using various process parameters combinations are listed in Table5. For a given process parameter combinations significant differences from the mid-centre of the interface ranging (341 VHN) to (402.5 VHN) were observed among the various welds, indicating that the process parameters influence the quality of the welded joints. Among the 9 welded samples S_5 and S_3 showed the highest (402.5VHN) and lowest (341VHN) hardness values respectively.

3.1.3 At Mid-Centre of Interface

The aim of this study is to evaluate the influence of the process parameters on hardness of the joint. Towards this study, Analysis of variance (ANOVA) was performed using the hardness as the response parameter (bigger- the –better), following standard ANOVA procedure, table7 and summarizes the ANOVA results, from these results as can be seen, rotational speed (C) and Burn-off (D) have the statistically significant influence on hardness of the joint sample5. Among these four process parameters, rotational speed and burn-off have the influence with 95% confidence level with higher hardness also the forge force (B) have the little influence on hardness, and the parameter friction force (A) within the parameter range selected in this study was found to be insignificant and therefore this parameter (A) is pooled as its f-ration is not falling in the considerable value.

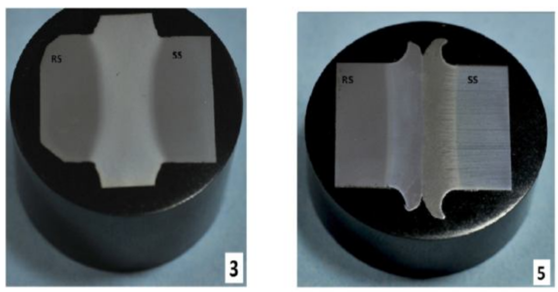
The result shows that for the sample 5 with the combinations of medium level of forge force (B), higher level of rotational speed(C) and low level of burn-off (D) have the minimum plastic deformation with lesser flash compare to the low hardness value of the joint sample 3 at the weld interface is obtained as explained in stage III . Based on the results obtained it should be noted that the optimum parameters reported here are specific to the material and its diameter used in the present work. Further the results were also dependent on the machine-specific as certain variables like brake timing, upsetting speed which can be of considerable influence on the outcome of the process.

3.1.4 At Centre of Interface

The hardness of the sample 5 is more at the centre of the face and here also the process parameters with higher level of rotational speed(C) and low level of burn-off-length (D)[15] influence is more significant and the process parameter friction force(A) is less significant but the process parameter forge force(B) is insignificant as its f-ration not falling the considerable value therefore it is pooled as shown in table 10.

3.*2 MACRO STRUCTURES*

The macro structures of friction welded sample 3 and sample 5 are shown in Figure, and with a magnification of 6X. The S3 can be related to the high flash and the sample S5 of little flash which is an indication of less plastic deformation due to less heat generation, on the other hand S5 showed less amount of flash due to less plastic deformation and gaining the fine grain structure, of all the nine (9) samples S_3 sample has more flash and more plastic deformation gaining coarse grain structure. The microstructures of sample 3 and sample 5 is shown below.



RS- Rotation side (Left side of the joint), SS- stationary side (Right side of the joint)
Fig 5: Macro Structures of Samples 3 and 5.

3.3 MICRO STRUCTURES

The micro structures of sample S3 having the low hardness and the sample 5 has high hardness among all the nine (9) samples, by observing the the microstructure of sample 5 it is of fine grain structure and is due to low friction force and less rotational speed causing little flash with less plastic deformation its cooling takes place rapidly giving fine grain structure, whereas the sample 3 welded with low friction force and higher levels of remaining parameters which results more plastic deformation with high flash which cools slowly resulting coarse grain structure[16] at regions corresponding to Centre and Mid-Centre are shown in figure 6.

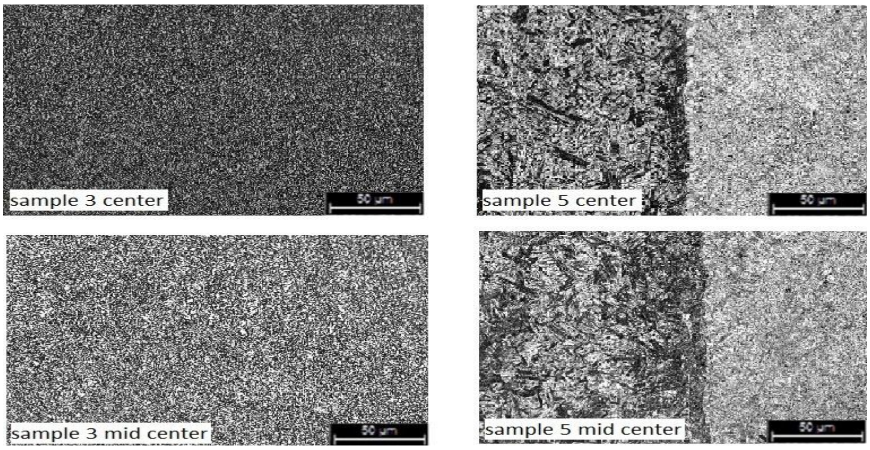


Figure 6: Micro structures of 15CDV6 Alloy Steel specimens 3 and 5 from Centre and Mid-centre.

CONCLUSIONS

The conclusion of the present work are enumerated and presented as shown here under.

1. The experimental investigations on the process parameters of 15CDV6 alloy steel reveal that sound joints of 15CDV6 alloy steel with the maximum hardness are achieved with a joint efficiency of 95% in pre-heat treated condition with careful selection of process parameters.
2. Rotational speed (2000) rpm and Burn off length (2mm) are the two most significant parameters are recommended to weld 15CDV6 alloy steel of 17mm diameter round rods.
3. In all the cases, the welds showed considerable differences in the amounts of flash and burn off with micro-structural differences from the interface to both rotating and stationary sides.

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