Reconditioning of Worn out Tyre Flanges by Automatic Submerged Arc Process

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Introduction

Rolling stocks are almost continuously guided by the wheel or tyre flanges on the track during service. It is no wonder, therefore, that portions of the tyre flange frequently abraded by the rail head, should wear out more than the tyre-tread, generally making only rolling contact with the rail table, in service. The relatively faster wear of the flange portion often results in thin and sharp flange tyres which make them vulnerable to derailment and hence the specified flange profiles on such wheel sets have to be restored from time to time to make them fit for service. The conventional method of reprofiling necessitates machining of substantial portions of tread thickness in case of thin and sharp flange tyres which reduce their effective service life considerably. Building up of the worn out portions by welding before reprofiling, dispensing practically with the necessity of wasteful machining of the tread for restoring the profiles, as may be observed from the illustration in Fig. 1, can increase considerably the effective service life or such tyres.

Work done in other Countries

Considering the advantages of reconditioning worn out tyre flanges by welding, many advanced railway systems in foreign countries have adopted various methods for building up of such tyres. A summary of these methods based on the report issued by the International Union of Railways is given in Appendix I which indicates that generally the following automatic processes have been adopted for reconditioning (i) bare wire welding process, (ii) submerged arc welding process, (iii) covered chain welding process, and (iv) CO_2 welding process. Of these, it has been reported that with the bare wire welding process, crack-free weld deposit was difficult to achieve. Although the other processes gave satisfactory weld deposits, it was observed that for high tensile steel loco tyres, having minimum tensile strength of 80 kg/mm^2, generally automatic submerged arc and CO_2 gas shielded welding processes were found to be suitable (Table 1).

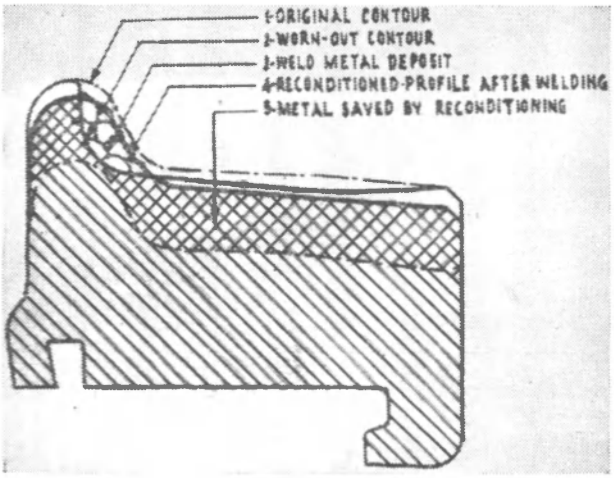

Fig. 1.

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TABLE 1

Tyres for locomotive wheels

Sl. No.	Administration	Material R(kg/mm^2)	Procedure	Treatment		Phase	Waste Percent	Multiplicator	
				Before	After			Duration of life	Price (Rs.)
1	DB(A)	Special Steel (a) R=100-115 (high speed rail cars)	Elarc	—	—	7	—	—	—
		(b) R=80-92	Elarc (Mantel ketten)	Cleaning, slow pre-heating 250-300°C.	Slow cooling 12-14 hours Turning.	1	2	1	0.3
			(Submerged arc)	,,	,,	2	2	1	0.2
			(CO_2 gas shield)	,,	,,	3	2	1	0.2
			Calor	,,					
				Ultrasonic test(plain)	Magnetic flux test of each tyre.	3(2)	5	2	0.2
2	FS	Steel R=75-85		Not worked up		7	—	—	—
3	SJ	Steel R-70	(a) Elarc	—	—	7	—	—	—
			(b) Calor	—	—	3	—	—	—
4	JZ(A)	Steel	(a) Elarc	Cleaning or turning pre-heating 200°C	Protected slow cooling	1	5	0.8	0.3
		UIC R=80-94	(b) Elarc (gas shield)	With pre-heating.	Under cap 10 hours cooling	2	—	—	—
5	CFF(A)	Steel St 80.11 R=80-90	(a) Elarc (CO_2 gas shielding)	Preheating 250-300°C	Draught Shielded cooling	1	0	0.8	0.3
			(b) Calor	—	—	6	—	—	—
6	DBB(A)	Special Steel R=80-90 monalloyed	(a) Elarc (Autom Mantelketten)	Turning whilst economizing on material	Slow cooling, turning.	1	—	—	—
			(b) Calor (Flame hardening)	Plaining (plain)	Hardness Test.	1	—	—	—
		Tempered special steel and alloyed steel.				7			

The abbreviations indicate in column 2 "Administration" SJ—Swedish State Rlys., CFF—Swiss Federal Rlys., FS—Italian State Rlys., JZ—Yugoslavian State Rlys. DB—German Federal Rlys.: in column 4 "Procedure" Elarc—Electric Arc, Calor—Heat Treatment (hardening, tempering & annealing) and the figures in column 7 "Phase" 1—In general use, 2—Large scale test (test in service) 3—Small scale test, 4—Tests envisaged. 6—Procedure abandoned, 7—Prohibited, 8—Rejected straightaway by reason of lack of economy.

Selection of the Process

It was planned that the first series of experiments and trials would be conducted on wagon wheels and after success is achieved, such experiments and trials may be extended to wheel sets fitted to coaches and motive powers.

The experience of the German Federal Railways indicated that satisfactory weld quality could be achieved by submerged arc process on tyres having specified tensile strength 80—92 kg/mm², and containing upto 0.65% carbon, 0.59 to 0.72% manganese and 0.21 to 0.40% silicon. The tensile strength specified for carriage and wagon tyres conforming to Indian Railway Standard Specification R-15 is 78 to 90 kg/mm². Fifteen such tyres, selected at random, gave the range of composition :—Carbon 0.43 to 0.69%, Manganese 0.37 to 0.78% and Silicon 0.15 to 0.30%. The similarity of the chemistry between the tyres, successfully welded by the German Federal Railways and the carriage and wagon tyres of the Indian Railways is apparent and supported the case for adoption of automatic submerged arc welding process for the experimental work undertaken in R.D.S.O. on carriage and wagon tyres. Besides, it was also considered that facilities for automatic submerged arc welding of wheel tyres could be easily made available in R.D.S.O. laboratory and also that suitable indigenous consumables could be readily procured for the experiments.

The reclamation experiments were, therefore, undertaken with the submerged arc welding process.

Important considerations in Automatic Submerged Arc Welding of Tyres

During submerged arc welding of tyre flanges, different types of cracks may form in the weld and heat-affected zones (HAZ) viz., hot cracks, contractional cracks, HAZ cracks and cracks initiated from internal or external discontinuities.

Hot cracks :—These are inter-crystalline tears in weld metal occurring at or just below the range of solidification of the weld metal. In submerged arc process, the current used is higher than that used in manual metal arc process. As a result, the degree of dilution of weld metal with parent metal is more, resulting in pickup of larger amounts of carbon, sulphur and other elements. These make the weld deposit more prone to hot cracks. After extensive investigations, British Welding Research Association has suggested that to safeguard against hot cracking, weld metal should contain : Sulphur 0.035% max. Manganese 0.80% min., Mn/S ratio 18 min, and Carbon 0.12% max. Elements, such as Mn, Mo, V and Cr improve the strength and ductility of the deposit, promote stabilisation of ferrite and ensure high Mn/S ratios. Some of these elements are also incorporated, therefore, either in the electrode wire or flux to minimise hot cracks. It is also necessary as a further safeguard to keep down the current as low as feasible with proper adjustment of other factors such as, wire size, speed, arc voltage etc. to achieve the desired minimum penetration on the tyre flange. The effects of these welding factors on the shape, size and penetration of weld are shown in Table 2.

Contractional cracks :—These are longitudinal cracks formed in weld metal when it can not withstand contractional stresses due to heavy restraint occuring from rigidity, mass and thickness of the joining members. To overcome this defect, minimum size of fillet has to be ensured mainly from consideration of thickness of the members to be welded. As the technique adopted

TABLE—2

Effect of welding conditions on shape, size and penetration of welds.

Weld characteristics	*Effect of increase in*				
	Welding current	*Electrode size*	*Arc voltage*	*Welding speed*	*Flux grain size*
Penetration	Increases	Decreases	Decreases slightly	Decreases at over 40 m/h	Decreases slightly
Width of Weld	Increases slightly	Increases	Increases	Decreases	Increases slightly
Re-inforcement	Increases	Decreases	Decreases	Increases slightly	Decreases slightly

for automatic submerged arc welding required deposition of the 1st run on the root of the worn flange as in the case of fillet weld, it was necessary to deposit at least a minimum size fillet having 3/8″ leg length. During the actual experiments, however, it was observed that this large fillet could cause high penetration leading to hot and HAZ cracking. This observation led to the adoption of a technique in which the first run was deposited about 6—8 mm away from the root of the flange with a smaller bead size having throat thickness about 4 mm to minimise weld dilution in subsequent passes.

Heat-affected zone cracks :—The heat affected zone cracks in tyre steels may result from (a) constraint which depends on the geometry of the section, (b) contour of the weld deposit and welding technique, (c) from formation of brittle martensite in the heat affected zone adjacent to the weld depending on the rate of cooling after welding, (d) chemistry of the tyre material, and (e) from hydrogen dissolved in the weld bead and its diffusion into parent metal. Atomic hydrogen is soluble in austenite at all temperatures but practically insoluble in cold ferrite or martensite. When the HAZ transforms, therefore, atomic hydrogen is rejected and tends to collect in inclusions, pores, and submicroscopic defects to form molecular hydrogen which cannot diffuse easily and therefore builds up high pressure adding to the contraction stresses. The moisture should, therefore, be expelled as completely as possible from the flux just before use by thorough pre-heating to minimise under bead cracks and shatter cracks or flakes due to hydrogen absorption. The moisture content in the flux should be preferably below 0.2 per cent.

Cracks initiated from discontinuities :—These develop in service in weld metal from imperfections such as, porosity, inclusion, lack of root penetration and from other types of cracks present. Therefore, moisture in fluxes, which is the main source of porosity, should be driven out by preheating. Care should be taken to avoid undercuts which may form due to wrong electrode angle or current or improper lateral shifting after each run during welding. Prior to welding, cracks, flat spots, shellings and scales, if present, should be removed by grinding as necessary.

Hardness :—The hardness of the built up portion of the tyre flange should be more or less similar to that of the tyre material by selecting suitable wire flux combination. The HAZ hardness should not be allowed to exceed 350 DPN to minimise the tendency of HAZ crack formations.

Flux :—Basic flux is preferred to provide a reducing slag to combine with oxygen and sulphur evolved from ferrous oxides and sulphides respectively. Where high sulphur is not a problem, flux containing high silicon is also employed which acts as a powerful deoxidiser on the molten filler metal. Besides the above, alloy ingredients viz. Ferromanganese, Ferrotitanium Ferrochrome etc., are also incorporated in the flux to improve specific characteristics of the weld deposit.

Electrodes :—Either the combination of standard electrode quality mild steel wire and a flux having adequate alloying elements, particularly manganese or the combination of "high Mn" wire, having approx 2% and suitable flux should be used for reclamation, the main aim being to deposit weld metal of strength, ductility, hardness and wear resistance comparable to those of parent tyre material.

Preheating :—Preheating is essential for minimising hardening and crack sensitivity of the heat-affected zone, by retarding the rate of cooling.

Weld sequence :—After cleaning of the tyre, prior to welding, the worn out profile should be checked for assessing the number of layers of weld metal to be deposited to provide enough metal to enable the reclaimed wheels being reprofiled to the new gauge with minimum machining of the tread. After building up of one layer of passes, if it is found that insufficient metal has been deposited in radius or in some other local areas, attempt should not be made to build up these local areas by putting one or two additional runs as these may cause cracks; instead, the whole operation from preheating should be repeated and another complete layer of passes should be deposited over the first layer of passes.

Tyres used :—Experiments were conducted on 22 condemned Broad Gauge carriage and wagon tyred wheels having worn out flanges, by the automatic submerged arc process, using different wire-flux and current-speed combinations.

Manipulator :—The variable speed drive manipulator, set up for rotation of wheels for the experimental work, is shown in Fig. 2. The driving unit consisted of a 3 H.P., 1440 rpm induction motor, a pair of reduction gears (30 : 1 and 7.25 : 1 ratio), a pair of auto-manual and tension pulleys linked by means of a specially designed Vee belt and four strands of single strand (25.4 mm) pitch roller chains of suitable length set in interchangeable sprockets.

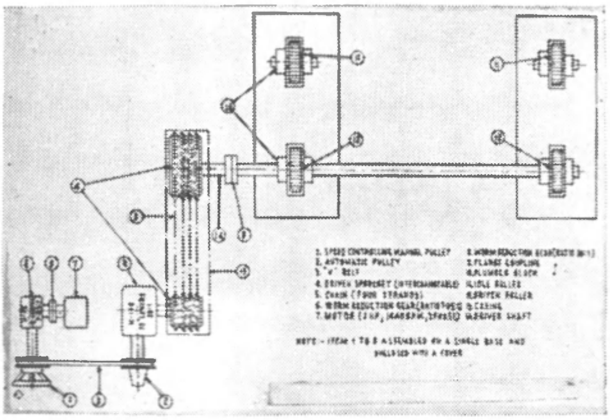

Fig. 2

Welding platform :—A platform for keeping the submerged arc welding machine was fabricated and fixed at a suitable height to enable welding being carried out from flange root to flange top for broad gauge carriage and wagon wheels without any difficulty by operating the vertical height adjustment provided in the submerged arc welding machine.

Welding machine :—Single head submerged arc welding machine and D.C. power sources were used for the experimental work.

Earthing arrangement and flux guard :—The earthing arrangement is shown in Fig. 3. It consists of woven copper braids, copper bus bar and spring to keep the earthing clamp in tension. Earth connection was given directly to journal end by fixing up the copper braid over the journal surface. The spring keeps the copper braid in good contact with the journal surface.

A suitable flux guard made from mild steel sheet lined with asbestos was made and fixed in contact with the flange top surface during welding.

Welding consumables, particulars, technique etc.,

Fluxes and wires used :—Two types of wire were used in the experiments viz., (a) copper coated mild steel wire and (b) copper coated high manganese wire having approximately 2 per cent manganese. Altogether three different brands of wires were used—two were of the mild steel type and one was of high manganese type.

Two different types of fluxes were used viz., (a) fused flux and (b) agglomerated flux. In all, five different brands of fluxes were used during the experiment.

Fused flux :—Fused flux is prepared by fusing the flux ingredients and then tapping the molten flux in the form of a thin jet into a stream of cold running water where it solidifies in the form of small particles which are then dried and screened to desired sizes. Particles of fused fluxes are chemically uniform. This type of flux does not absorb moisture and therefore does not require preheating before use.

Agglomerated flux :—Agglomerated flux is a mechanical mixture of the ingredients. The ingredients are powdered and thoroughly mixed with water glass to form a paste. The paste is then granulated through a sieve or by any other suitable technique. The grains are then dried and stored. This type of flux readily absorbs moisture and requires proper storage and drying at 250-300°C for at least one hour in layers not more than 25 mm in depth immediately before use. This type of flux has poor bond strength and becomes powdery with use and hence cannot be re-used many times.

Six different combinations of wire and flux (indigenous as well as imported) were used for the experimental work.

Welding particulars and technique :—Experiments were carried out at various combinations of current—speed—flux—wire on the 22 experimental tyres till the optimum wire-flux combinations and current-speed-wire size conditions, for achieving minimum penetration into high carbon tyre required for satisfactory crack-free deposit (as discussed above) were standardised.

Grinding was carried out, using baby pneumatic grinders having $2\frac{1}{4}''$ dia $\times$ $7/8''$ thick $\times$ $3/8''$ bore wheels, only on wheels with rusty corrosion pits, otherwise only emery paper was used.

Agglomerated fluxes were preheated between 250°—270°C for one hour immediately before use. Fused fluxes were not preheated.

The tyres were preheated to 300° to 350°C before welding using one air-petrol burner and one oxy-acetylene flame cleaning blowpipe, fitted with round nozzle with multiple orifices, at two diametrically opposite points on the tread portion. The tyres were soaked in the preheating temperature for at least 15 minutes. Preheating takes about 45 minutes.

The welded wheels were not subjected to any post heat-treatment, but the wheels, immediately after welding, were cooled slowly under cover of asbestos lined hoods.

Welding position, sequence etc. :—Welding was carried out in flat position. The wheel set was kept in running position and rotated in the wheel manipulator at the desired speed thereby permitting the tread to lie in a horizontal plane and the tyre flange to lie in a vertical plane. After earth connection to the journal of the wheel, as shown in Fig. 3, deposition of weld metal was started on the tyre tread, about 12 mm away from the root of the worn flange in the flat position. As welding progressed, the nozzle with the electrode was shifted laterally to required increments, depending on the shape of the worn profile, after completion of each circumferential run. The angle between the electrode and the vertical axis was also adjusted as per requirements and kept in the range 5°-15° during the experimental work. The electrode was positioned 25 mm to 50 mm away from the vertical axis of the wheel in the direction opposite to the direction of rotation with a slight inclination to the vertical so that the projected centre line of the electrode passes through the centre of rotation of the work. Fig. 4 shows the submerged arc welding operation of a worn out tyre flange in progress during the experimental work undertaken in RDSO/Chittaranjan.

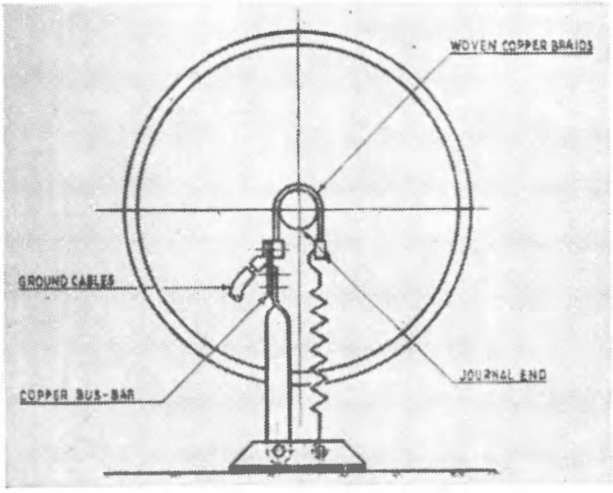

Fig. 3.

Metallurgical Investigations

Visual examination : Visual examination carried out carefully on each run during welding revealed that out of 22 wheels, 10 tyres welded during the second phase were free from cracks and other harmful defects revealing that the welding parameters used for building of these ten tyres were satisfactory and gave consistent results. Out of the remaining 12, 3 samples revealed

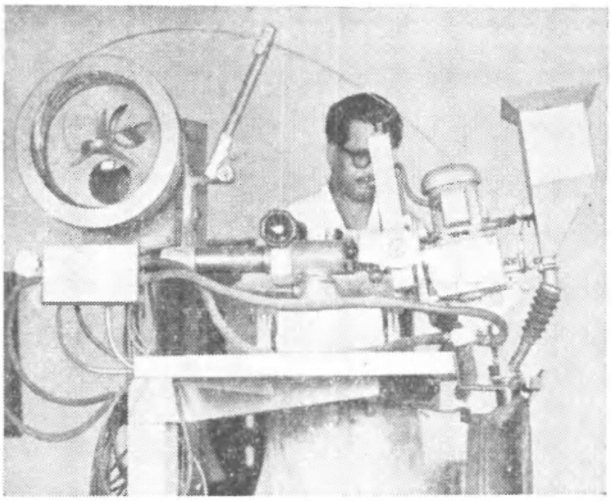

Fig. 4.

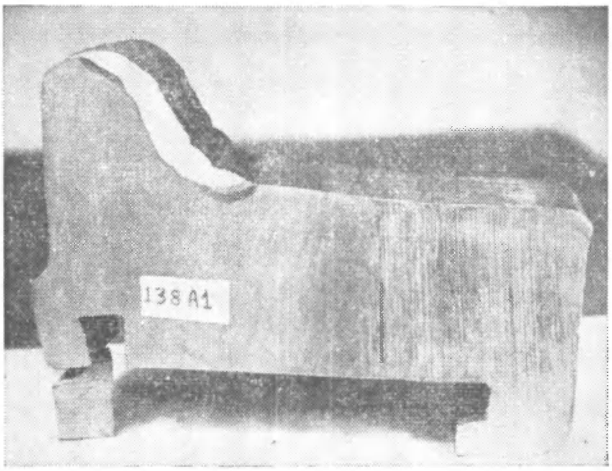

Fig. 5.

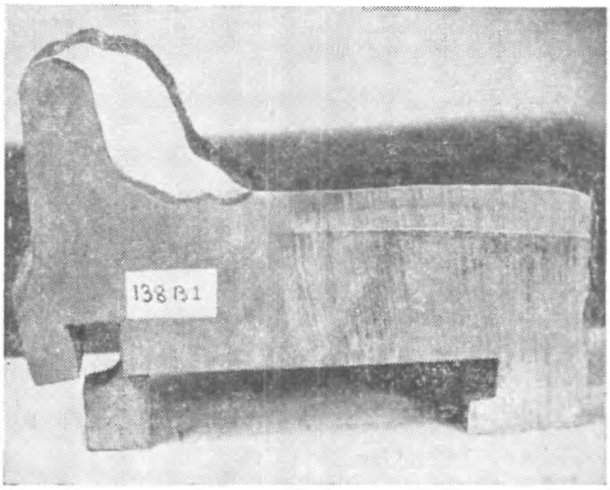

Fig. 5A.

one or two cracks in the first run only which can be eliminated during machining for reprofiling.

Chemical analysis : Chemical composition of electrode wire used and weld metal deposited on the 15 tyre samples, analysed previously, were determined with a view to finding out the percentage dilution of the weld metal with the parent metal and also the chemistry of the weld deposit required for freedom from cracks.

Macro examination : The tests were carried out on the experimentally welded tyres on transverse and logitudinal sections, cut through the weld, HAZ and the parent tyre.

Figs. 5 to 8 show photomacrographs of transverse and longitudinal sections cut from a few welded tyres, revealing satisfactory and unsatisfactory quality of weld deposit.

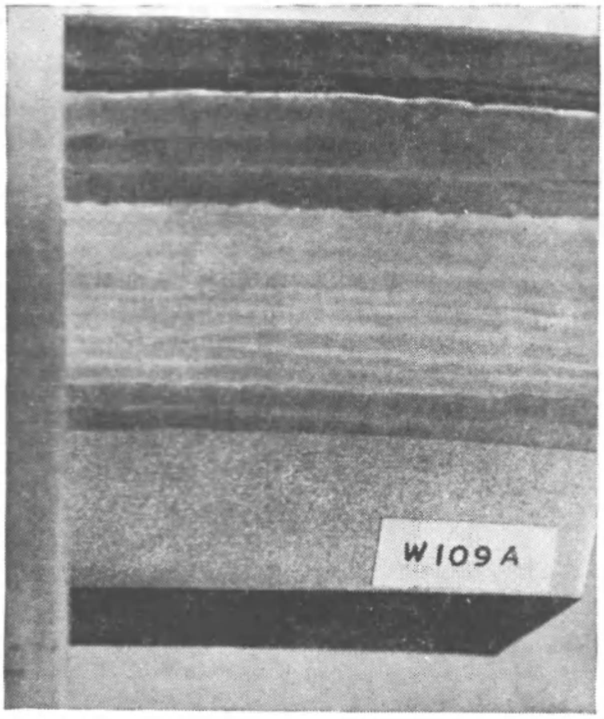

Fig. 6.

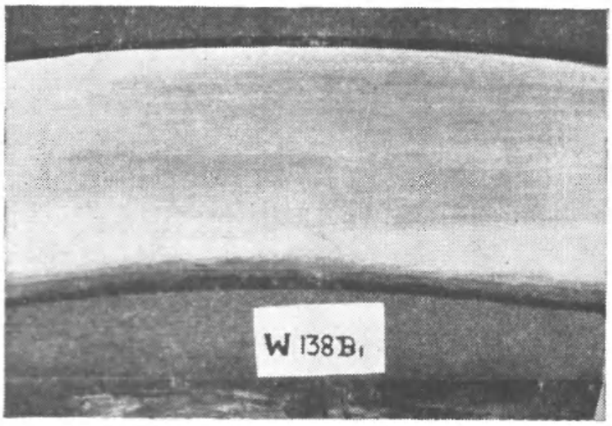

Fig. 6A.

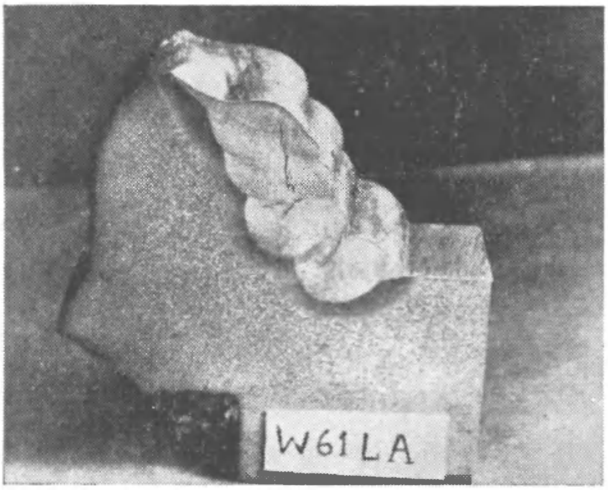

Fig. 7.

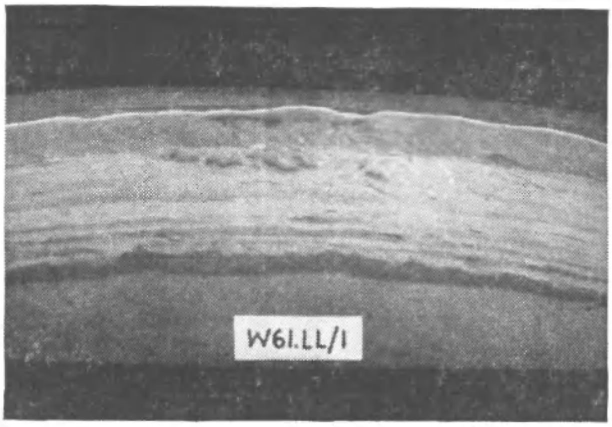

Fig. 8.

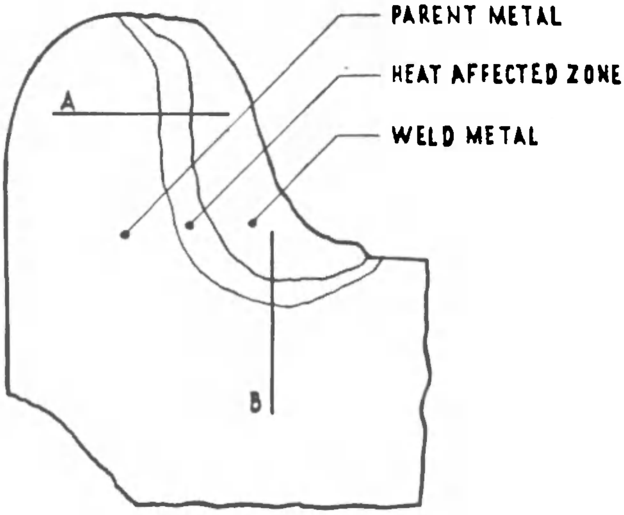

Fig. 9.

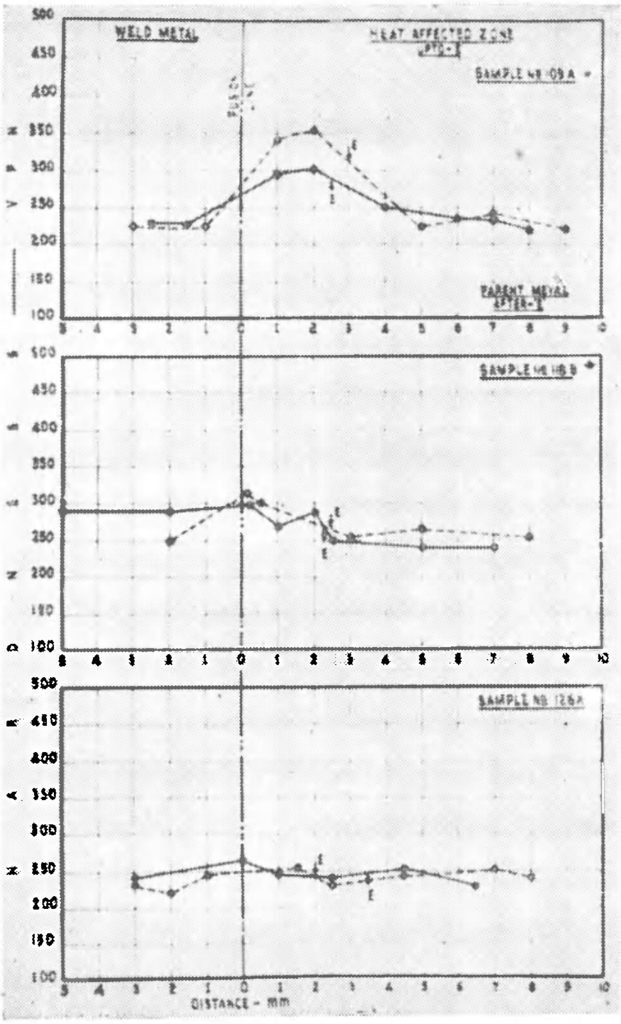

Fig. 10.

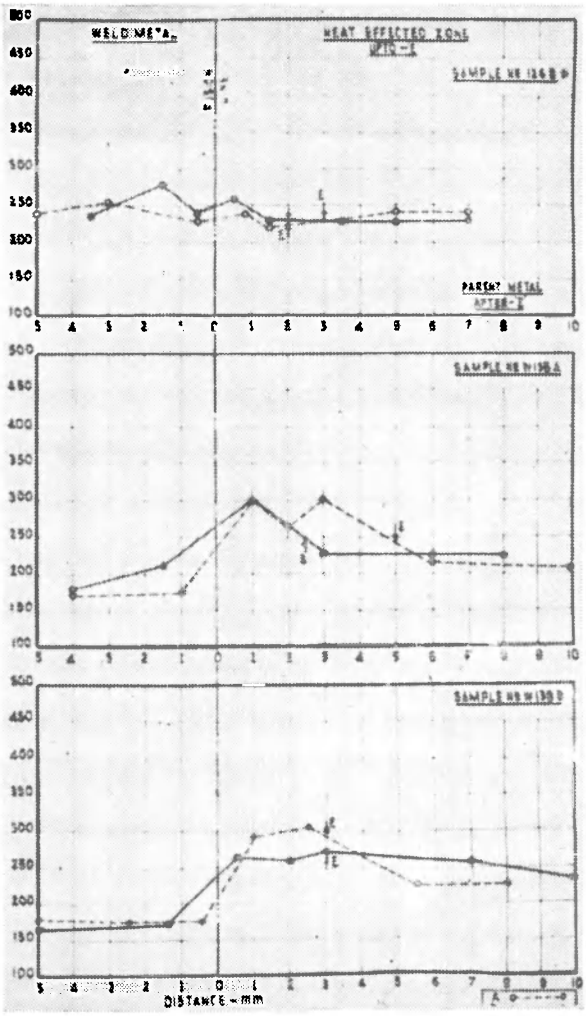

Fig. 10A.

Hardness Survey : Vickers hardness survey using 30 kg load was carried out on transverse section along two lines A & B as shown in Fig. 9. The variation in hardness across weld, HAZ and parent metal of the transverse section of the reconditioned tyres giving satisfactory and unsatisfactory welds are graphically represented in Figures 10 & 11 respectively.

Vickers hardness survey was also carried out on longitudinal sections using 30 kg load through weld, HAZ and parent metal. Typical examples of the values obtained on satisfactory and unsatisfactory samples are tabulated (Table 3).

Magnetic crack detection : The transverse and longitudinal sections of the tyre samples which did not reveal cracks on macro-examination were subjected to magnetic crack detection tests. Out of 6 samples, which revealed satisfactory quality during micro-examination on transverse and longitudinal sections, 3 samples were found to contain one or two fine cracks in the first run welded on the tread portion which would get eliminated during reprofiling.

Findings of metallurgical investigations :— Chemical analysis revealed that both indigenous and imported mild steel quality wires used in the experiments were of standard quality and conformed to IS : Specification 2879. Chemical analysis of experimental tyres revealed that the carbon content of IRS Carriage and Wagon tyres varied between 0.43% and 0.69% which are higher than those usually obtained on foreign carriage and wagon tyres and hence weldability of IRS tyres are generally much inferior to foreign carriage and wagon tyres. Chemical analysis of weld deposit revealed that in case of crack-free deposits the carbon content of the weld deposit varied between 0.11% and 0.18% (average 0.15%) and Mn content varied between 1.26% and 1.44% (average 1.36%). For weld deposit containing a number of cracks the carbon content

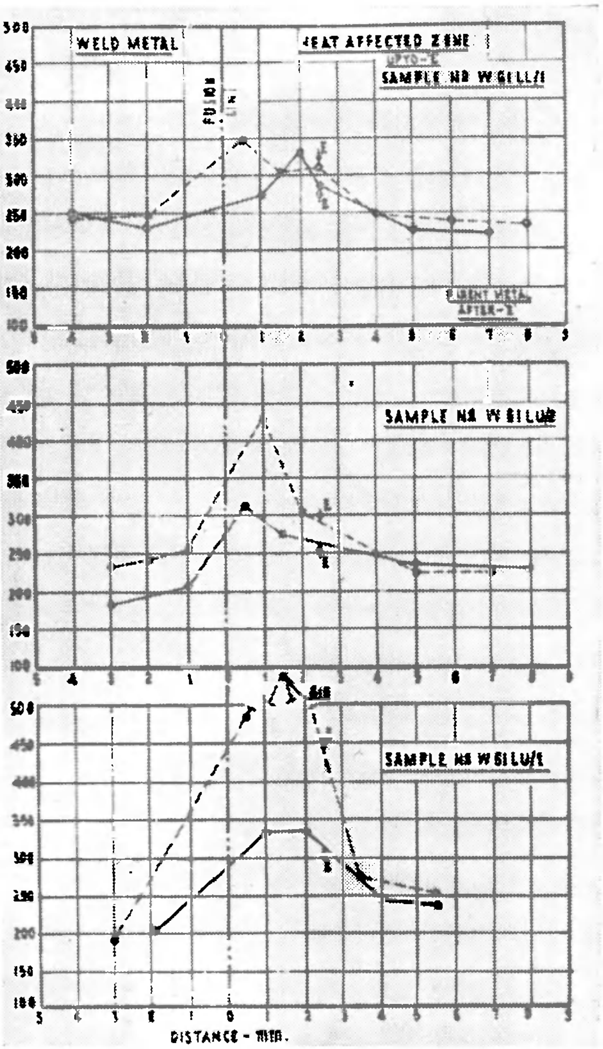

Fig. 11.

varied between 0.11% and 0.28% (average 0.18%) and manganese content varied between 0.61%—1.42% (average 1.04%). Mn/S ratio of weld deposit in case of satisfactory samples was found to be in the range 65 to 102, whereas in case of unsatisfactory samples having a large number of cracks, the ratio varied between 26 and 60.

Macro examination revealed that it was possible to obtain optimum current—speed—wire size combination for achieving satisfactory and crack-free weld deposit. The three samples which revealed one or two fine cracks in the first run only, detected on magnetic test were further investigated and found to be confined within the first run only. These cracks could, however, be eliminated from the first run by (a) light filing removing about 0.025 mm from the tip of the deposit containing cracks before depositing the second run (b) by dissolving as much of the first run as possible (about 25% to 30%) by reducing the speed by 5% and simultaneously increasing the welding current by about 5% and (c) by positioning the first run so that it gets eliminated during reprofiling of the tread by machining.

Hardness survey revealed that the hardness variation in weld, HAZ and parent metal was gradual and peak HAZ hardness was upto 300 VPN approx. in samples which were pre-heated in the range of 300-350°C whereas in case of samples preheated to 200-250°C hardness variation was abrupt and peak HAZ hardness was very high.

Conclusion

The experimental work and metallurgical investigation revealed that IRS carriage and wagon tyres can be welded satisfactorily by the submerged arc process by following the standardised procedure and technique. The following two combinations of wire size-current-speed-arc voltage have given satisfactory results during the experimental work and are recommended to be followed for submerged arc welding of IRS carriage and wagon tyres.

	Combination **1**	*Combination* **2**
Wire size (mm)	4	3.25
Current (amps)	350	300
Speed (inch/min)	35	30
Arc voltage (volts)	30	28

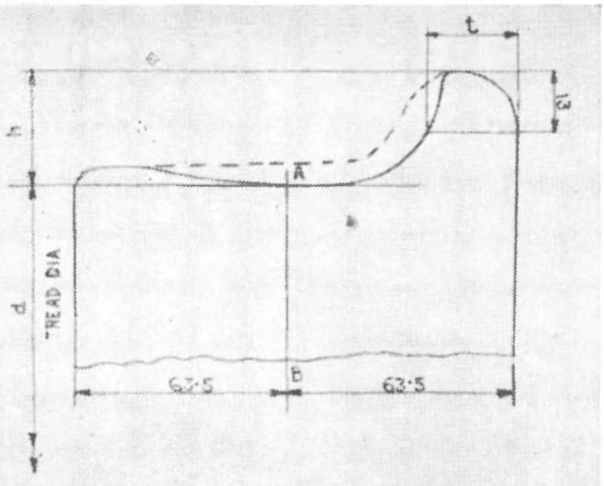

FIG. 12. WORN OUT TYRE PROFILE SHOWING FLANGE THICKNESS t AND FLANGE PROJECTION h.

Fig. 12.

Economics

Detailed sample survey was carried out at Alambagh Shops/Lucknow on 200 worn out Broad Gauge Carriage and Wagon wheels, selected at random from the wheels received for periodic overhaul. The different types of wear patterns of these wheels were recorded carefully with measurements of flange thickness (t) and flange projection (h) as shown in Fig. 12. The survey revealed that out of the tyred wheel sets about 29% of wheel sets have thin and/or sharp flanges worn to the minimum workshops limit of 17-22 mm flange thickness requiring one layer of weld deposit on each tyre of the wheel sets and 10% with thin flanges between 17-22 mm flange thickness requiring one layer of weld deposit on one tyre only. These two categories, totalling to 39% will yield substantial economy if reclaimed by welding. It was further observed during the survey that the material available on the tread section of tyres for re-turning is 32 mm and average cut required during re-turning on the tread in case of unwelded and welded thin and sharp flange tyres are approximately 16.3 and 2.43 mm respectively. Therefore, the unwelded thin flange tyres can be subjected to only about two cuts (32/16.3 = 1.93=2 approx.) each after 3.3 years approx. (average interval between two periodic overhauls) and the welded tyres can be subjected to 13 cuts approx. (32/2.43 = 13.10 say 13). Hence, the estimated average life of thin and sharp flange tyres reconditioned by machining is about 10 years as against more than 40 years for such tyres reconditioned by welding.

Economics calculated on these two categories of tyres constituting about 39% of the tyre population was estimated to yield a saving of about Rs. 20,00,000 per annum.

TABLE 3

Sl. No.	*Sample No.*	*Hardness Survey*		
		Weld metal DPN	*HAZ metal DPN*	*Parent metal DPN*
Satisfactory Samples				
1	126A	241, 265, 253, 241, 265	230, 220 241, 265	245, 252 240, 230
2	138A	214, 177 177, 171	301 301, 301	223, 214 223, 214
3	138B	177, 177 177, 177	269, 252 294, 275	252, 241 223, 223
4	W109A	227, 204 244, 239	286, 274 321, 321	244, 251 229, 227
5	W118B	252, 244 251, 268	301, 287 274, 270	264, 252 245, 251
6	126B •	230, 201 253, 241	241, 210 252, 241	230, 230 230, 241
Unsatisfactory Samples				
1.	W61LL/1	247, 247 252, 232	348, 301, 308 275, 331, 287	247, 237, 232 227, 223
2.	W61LU/2	232, 242, 252 184, 206	429, 301 315, 275	223, 223 232, 227
3.	W61LU/1	193 206	481, 615 335, 331	263, 256 245, 242