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Mechanical Properties of Hot Rolled Ribbed and Plain Steel Rods

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ABSTRACT: This study focuses on microstructure and mechanical behaviour of 3PS (Semi-killed mild steel) hot rolled ribbed and plain carbon steel. 3PS billet steel samples and hot rolled ribbed and plain steel rods of different heat numbers and profiles were characterized for its chemical composition, microstructure, and tensile behaviour. The composition analysis of 5 (five) 3PS billet samples shows that there was no appreciable variation in chemical composition of the hot-rolled plain and ribbed steel rods. The microstructures of as-received steel billet (3PS) examination revealed large grains of ferrite and pearlite while those of hot-rolled 3 PS mild steel samples of different heat numbers contain smaller grains of ferrite and some amount of pearlite. The results also indicated that yield and ultimate tensile strength reach maximum values (492 and 361 N/mm^2) at 0.31% elongation for heat number 43 while maximum values for heat number 56 (478 and 362 N/mm^2) at 0.33 % respectively. The ribbed steel rod of the same diameter as plain steel exhibit slightly better mechanical properties with higher values of yield and ultimate tensile strength. There is consistency in the chemical composition of the as-received billet and the hot rolled products.

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Plain carbon steels account for about 80% of all metals used for industrial applications (Mridha, 2016; Aggen et al., 2018) because of their low costs and ease of fabrication (Callister Jr. and Rethwisch, 2012). They can be formed into desired shapes with precise specifications through mechanical processes such as rolling and forging (Bell, 2017; Materials, 2012; Charlie, 1996; Atanda et al., 2015). Plain carbon steels are machinable, workable and heat treatable providing a wide range of mechanical properties such as yield strengths (200–300 MPa) (Hata et al., 2004). On the basis of heat treatment, killed, semi-killed and rimmed steels can be produced. Semi-killed steel is characterised by variable degrees of uniformity in composition which is intermediate between killed and rimmed steels. Typically, more gas is evolved in semi-killed steel than in killed steel but less than in rimmed or capped steel. For all practical purposes, steels are categorized based on the amount of carbon contents which are hypoeutectoid steels (0.025-0.8 wt% C), eutectoid steel (0.8 wt% C) and hypereutectoid steels (> 0.8 wt % C) (Cheng et al., 2013). The properties of hot rolled ribbed and plain steel rods are influenced by several processing parameters such as degree of rolling and temperature among others. Zhuang and Di (2006) showed that the degree of rolling and temperatures significantly influenced microstructural and mechanical properties of hot-rolled multiphase steels. Polygonal ferrite, granular bainite, and a considerable amount of stabilized austenite were obtained by thermo mechanical processing. The results also indicated that ultimate tensile strength and total elongation reached maximum values of 791MPa and 36%, respectively. The grain refinement as the only commercially available conventional technique which improves strength and ductility at same time was reported by (Zhuang and Di, 2006). They have noticed an excellent relationship between yield stress and grain size in the development of high strength low alloy (HSLA) steels. His finding shows that coarse grained steel has better hardenability than fine grained steel. Obikwelu, (1987) investigated the optimization of mechanical properties of rolled products and discovered that most mills in developing nation of the world still operated on the basis of conventional rolling which was devoid of modern facilities offered by controlled rolling. He observed that conventional mills were not executed along with the necessary temperature monitoring with a view to controlling the evolved microstructures. Saroj, (2010) reported that steel bars produced through conventional rolling often demonstrated low mechanical properties. He noticed that inter-stand temperature such that the desired initial austenite grain size is achieved and this would ensure that appropriate of morphology, grain size and texture during cooling of the bars. Zhang et al. (2017) reported effect of rolling process parameters on the mechanical properties of hot-rolled St60Mn steel. They concluded

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that increasing the rolling strain rate from 6.02851 x 10^3 s^{-1} to 6.10388 x 10^3 s^{-1} using % total deformation of 99 % and finish rolling temperature of 958 ^oC enhanced the mechanical properties of St60 Mn steel. In the light of the above, current study focuses the effect of hot rolling on the mechanical properties and hot rolling of industrial products (steel rods of different profiles).

MATERIALS AND METHODS

Five samples of semi-killed mild steel (3PS) (billets steel grade with different heat treatment numbers and hot rolled products of the different profiles) were prepared at Ajaokuta Steel Company Limited, Kogi State, Nigeria. The standard composions of similar samples based on the laboratory's reports submitted to the Industry–German standard (DIN 380-94) are provided in Table 1.

Table 1: Chemical Composition based on Laboratory's reports submitted to the Industry –German standard (DIN 380-94)

Heat No.	Steel Grade	Profile mm	Chemical Composition				
			C	Si	Mn	Pb	S
036	3PS	125	0.161	0.059	0.314	0.009	0.013
043	3PS	125	0.156	0.051	0.513	0.009	0.013
056	3PS	125	0.183	0.056	0.552	0.009	0.013
058	3PS	125	0.164	0.055	0.490	0.008	0.012
061	3PS	125	0.172	0.070	0.567	0.045	0.041

The samples (measured 40 x 50 x10 mm^3) were unidirectionally hot rolled at a temperature of 1045^oC for three passes such that a 2 mm thickness reduction was achieved after each pass. The samples were characterized for microstructure, ultimate tensile and yield strength before and after hot rolling using optical microscope and computer controlled servo-hydraulic tensile testing machine, respectively. The samples for microscopy were prepared by grinding and mechanical polishing followed by etching in picral reagent. The fineness of lamellar structure was measured by the true interlamellar spacing, λ_0 (Ridley, 1984) while the grain size and large α platelets were estimated from the optical images. Tensile tests were carried out at room temperature by a computer-controlled servo-hydraulic facility (Instron model 8502) at a crosshead rate of 1 mm/min using samples machined following ASTM-E8 standard.

RESULTS AND DISCUSSION

Chemical compositions of the samples: The compositions of the samples (Table 2) are similar to the DIN 380-94 standard composition (Table 1) indicating that the samples comform with the industry's standard. The implications of variance in carbon contents could lead to decrease in ductility, machinabilty and weldability of the steel. Similarly, the manganese which is also a neccesity for the process of hot rolling of steel and changes in their contents could steered to increase in the hardenability and tensile strength but decreases in ductilty of steel (Aghamir et al., 2018).

Microstructure and grain size analysis: Figure 1 shows the micrograph of as received (a,b) and hot rolled (c,d) steel samples for heat number 43 and 56. The as received steel samples indicated large grains of ferrite and pearlite while hot rolled 3 PS mild steel micrographs appear to contain smaller grains of ferrite and some amount of pearlite. The finer grain size of the hot rolled 3PS steel samples indicates improved yield strength and grain refinement. Table 3 and Table 4 present tensile test and composition analysis of mild steel samples for heat number 43 and 56 after hot rolling. The yield strength (YS), ultimate tensile strength (US) and percentage elongation for as-received before hot rolling 3PS (Heat number 43) were 333 N/mm^2, 461 N/mm^2 and 0.35%, while for (Heat number 56) were 316 N/mm^2, 445 N/mm^2 and 0.36 % respectively.

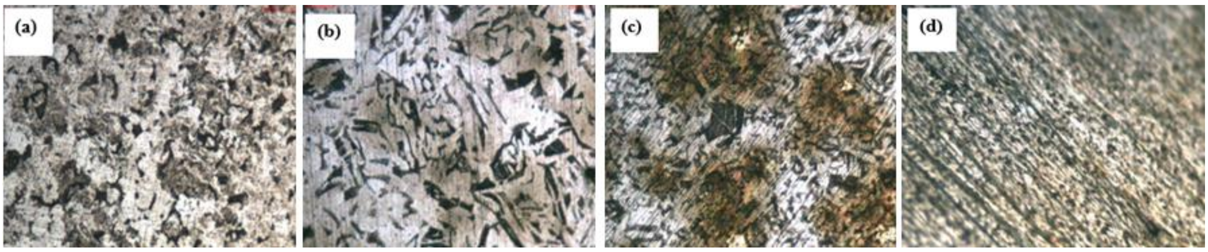

Fig 1: Optical micrograph of (a) as received billet heat No 43 (b) as received billet heat No 56 (c) Hot rolled steel rod heat No 43 (d) Hot rolled steel rod heat No 56

Table 2: Tensile test and composition analysis of mild steel samples before hot-rolling

Heat No.	Steel Grade	Profile mm	YS N/mm²	UTS N/mm²	Elongation %	Chemical composition				
						C	Si	Mn	Pb	S
036	3PS	125	290	417	0.39	0.161	0.059	0.314	0.009	0.013
043	3PS	125	332	461	0.35	0.156	0.051	0.513	0.009	0.013
056	3PS	125	316	445	0.36	0.183	0.056	0.552	0.009	0.013
058	3PS	125	330	445	0.34	0.164	0.055	0.490	0.008	0.012
061	3PS	125	303	445	0.40	0.172	0.070	0.567	0.045	0.041

Table 3: Tensile test and composition analysis of mild steel samples after hot-rolling Heat No 43

Heat No.	Steel Grade	Profile mm	YS N/mm²	UTS N/mm²	Elongation %	MILL	Chemical composition				
							C	Si	Mn	Pb	S
043	3PS	N12	333	458	0.35	WRM	0.170	0.053	0.055	0.0091	0.012
043	3PS	N10	339	463	0.34	WRM	0.241	0.070	0.567	0.045	0.041
043	3PS	N8	358	490	0.32	WRM	0.163	0.054	0.556	0.0094	0.013
043	3PS	ø08	361	492	0.31	WRM	0.163	0.054	0.556	0.0094	0.013

Table 4: Tensile test and composition analysis of mild steel samples after hot-rolling Heat No 56

Heat No.	Steel Grade	Profile mm	YS N/mm²	UTS N/mm²	Elongation %	MILL	Chemical composition				
							C	Si	Mn	Pb	S
056	3PS	N12	316	446	0.36	WRM	0.171	0.054	0.056	0.0091	0.012
056	3PS	N10	317	454	0.35	WRM	0.170	0.053	0.555	0.0091	0.012
056	3PS	N08	336	460	0.34	WRM	0.160	0.053	0.556	0.094	0.013
056	3PS	ø 08	362	478	0.33	WRM	0.160	0.053	0.556	0.094	0.013

The carbon content was 0.156 % and 0.183 % which is within the range of mild steel (Zhuang and Di, 2006). The chemical analysis on hot rolled steel rods of different profiles revealed that the values of YS and US decreases with decrease in the profiles of the hot rolled steel rods. By comparison of 3PS as received with hot rolled steel for heat number 43 and 56, it is clearly from the Table 2-3 that the YS, US and percentage elongation of heat number 43 and at 12 mm profile is increased by 0.3 % in YS, 0.65 % in US and 0.35% in elongation while at 8mm profile is increased by 8 % in YS, 6.3 % in US and 0.31% in elongation. The YS, US and percentage elongation of heat number 56 and at 12 mm profile is increased by 4.8% in YS, 2.62 % in US and 0.35% in elongation while at 8mm profile is increased by 0.33 %. The yield and ultimate tensile strength reach maximum value of 492 N/mm^2 and 361 N/mm^2 for heat number 43 while 478N/mm^2 and 362N/mm^2 for heat number 56 at both a profile of 8mm respectively (Figure 2). These results indicated that yield and the ultimate tensile strength increases with decrease in profile of mild steel samples.

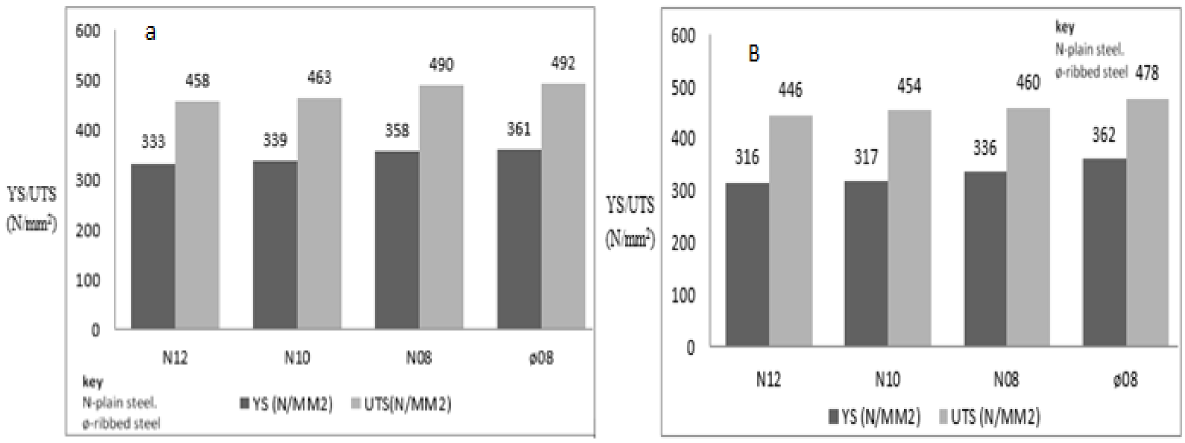

Fig 2: Response chart of hot rolled steel rod for the yield and ultimate tensile strength to profile for heat number (a) 43 (b) 45

Conclusion: The results of this research work showed that the chemical compositions of the hot rolled 3PS steel rod conform to industry standard as supplied by the manufacturer. The yield and ultimate tensile strength reach maximum value of 492N/mm^2 and 361N/mm^2 for heat number 43 while 478N/mm^2 and 362N/mm^2 for heat number 56 at both a profile of 8mm. The ribbed steel rod of the same diameter as plain steel exhibit slightly better mechanical properties with higher values of yield and ultimate tensile strength.

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