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Effect of hardening and tempering on microstructure and mechanical properties of steel grade AISI 5160

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Abstract

In this research, an as-sheet steel grade AISI 5160 was studied. The heat treatment consists of hardening at 850 – 1,050 °C for 30 – 120 minutes followed by quenched in water at 50 °C. Tempering was performed at 250 – 550 °C for 30 – 120 minutes followed by quenched in water. Microstructures were measured by optical microscopy (OM) and scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). For each condition hardness and tensile testing were measured. It was found that the microstructure in the as-sheet condition consisted of ferrite and pearlite. The resultant microstructures after hardening process are observed as lath and plate like of martensite with small amount of retained austainite. After the tempering process, the bushy type of tempered martensite and bainite was occurred. The hardness in the as-sheet condition was 40 HRC. The hardening increased the hardness compared to the as-sheet condition. Peak hardness was obtained 62 HRC after hardening at 850 °C for 30 minutes. However, after tempering, the hardness was slightly decreased while gradually increased ultimate tensile strength and %elongation due to the process reduced brittleness by plastic deformation and ductile fracture.

Keywords: Steel grade AISI 5160; Hardening; Tempering; Microstructures; Mechanical properties

1. Introduction

AISI 5160 steel is a high carbon and chromium steel used in the automotive field in a number of different heavy spring applications, especially for leaf springs due to its outstanding toughness, a high level of ductility, and excellent fatigue resistance [1]. Recent results have shown that the improvement in properties that is reached by quenching is of such magnitude that the content of alloying elements in steel can be reduced. Steels are normally hardened 830 – 870 °C [1 - 3] and tempered at 100 – 700 °C for 10 seconds [3] to 3 hours [1] to improve their mechanical properties, particularly their strength and wear resistance. In hardening, the steel or its alloy is heated to a temperature high enough to promote the formation of austenite, held at that temperature until the desired amount of carbon has been dissolved and then quench in oil or water at a suitable rate. Also, in the harden condition, the steel should have 100% martensite to attain maximum yield strength, but it is very brittle too and thus, as-quenched steels are used for very few engineering applications. The A1 temperature for the 5160 steel is about 710 °C and the A3 temperature decreases from 766 °C. The Ms temperature is 260 °C and the Mf temperature is 310 °C [4]. By tempering, the properties of quenched steel could be modified to decrease hardness and increase ductility and impact strength gradually. The resulting microstructures are bainite or carbide precipitate in a matrix of ferrite depending on the tempering temperature. Steel is an alloy of iron with definite percentage of carbon ranges from 0.15 – 1.50% [5], plain carbon steels are those containing 0.10 – 0.25% [6]. The reason for its importance is that it is a tough, ductile and cheap material with reasonable casting, working and machining properties, which is also amenable to simple heat treatments to produce a wide range of properties [7].

However, there is no evidence reported in the literature regarding the influence of the microstructure produced of intensively hardened steels on hardness and tensile Strength. Thus, the aims of this study was investigated the effects of heat treatment parameters on microstructure and mechanical properties of Steel grade AISI 5160.

2. Materials and methods

Materials preparation and heat treatments

An experimental of 5160 steel was prepared from 5160 grade of dimension 1.20 x 6 x 102 cm^3. The chemical composition of the steel is given in Table 1. The heat treatment composed of hardening, followed by quenching and further tempering. In this work, hardening was performed at 850, 950 and 1050 °C for 30, 60, 90 and 120 minutes followed by quenching into hot water at 50 °C with agitation rates 120 revolutions per minutes. Tempering was performed at 250, 350, 450 and 550 °C for 30, 60, 90 and 120 minutes followed by quenching into hot water at 50 °C with agitation rates 120 revolutions per minutes.

Characterization

The 5160-heat treatment samples were cut from the position and then ground on silicon carbide papers to 1,500 grit, and then progressively polished with 1 and 0.30 µm Al_2O_3. The etchant used for OM and SEM samples was 3% Nital, excepted for XRD samples. The SEM image and EDS spectra were measured on a LEO 1455LV. The XRD patterns were recorded on X′ Pert.

Table 1 Chemical composition (wt%) of the experimental sheet 5160 steel.

Elements	C	Si	Mn	P	S	Cr	Ni	Cu	V	Fe
wt%	0.58	0.23	0.77	0.02	0.01	0.73	0.04	0.03	0.01	Bal.

Hardness and Tensile measurements

Hardness testing was performed on un-etched specimens with a Rockwell hardness tester using the C scale (HRC) with 120° diamond cone, 150 kgf load and 15 seconds indenting time. The mean values are based on ten different areas on each specimen. Tensile testing was carried out using h10ks Hounsfield make tensile testing machine and test sample conformed to standard ASTM E8 round sample (50 mm gauge length).

3. Results and Discussion

Microstructural investigation

Fig. 1 shows the X-ray diffraction patterns in the as-sheet condition, after hardening at 850 °C for 30 minutes and after hardening at 850 °C for 30 minutes followed by tempering at 450 °C for 30 minutes. XRD result for as-sheet specimens revealed that the phases present were corresponding to single martensite phase (α′-Fe, i.e. α-Fe with carbon). However, for the hardened and tempered specimens, indicating that the retained austenite phase had been occurred in the microstructure.

Fig. 2(a) it can be observe the microstructures of ferrite and pearlite phase in the as-sheet condition. The microstructure at higher magnification in a scanning electron microscope consists of a highly ordered layered structure of ferrite (dark) and cementite (white) that sticks out of the ferrite matrix as shown in Fig. 2(b). Microstructure after hardening at 850 °C for 30 minutes is showing martensite structure in Fig. 3(a). SEM image in Fig. 3(b) was observed as lath and plate like of matensite. However, retained austenite was occurred to be stabilized by a pinning mechanism. During hardening treatment, carbon is redistributed by diffusion out of the martensite. The structure is then stabilized by interstitial carbon atoms pinning the austenite–martensite interface [8].

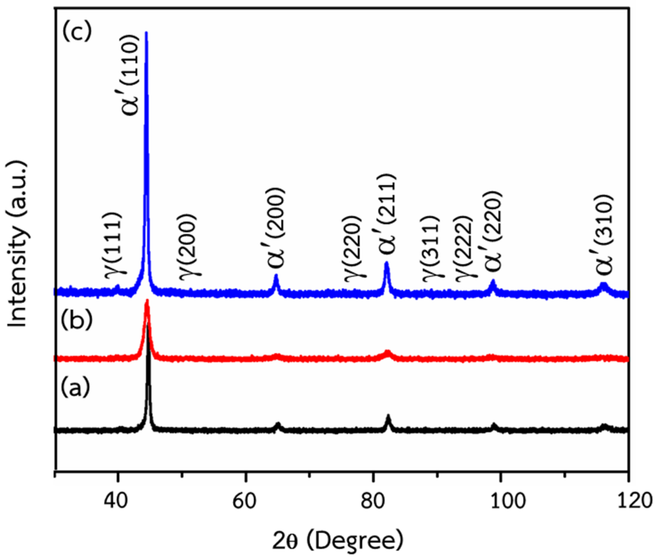

Fig. 1 X-ray diffraction pattern of (a) as-sheet condition (b) after hardening at 850 °C for 30 minutes and (c) after hardening at 850 °C for 30 minutes followed by tempering at 450 °C for 30 minutes.

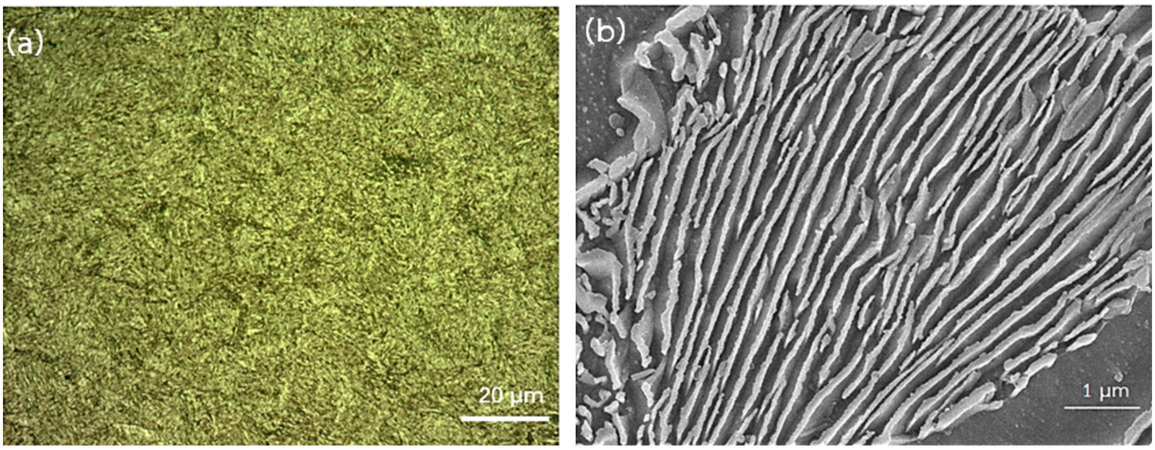

Fig. 2 Micrographs show the microstructure of as-sheet condition by (a) optical microscopy and (b) scanning electron microscopy.

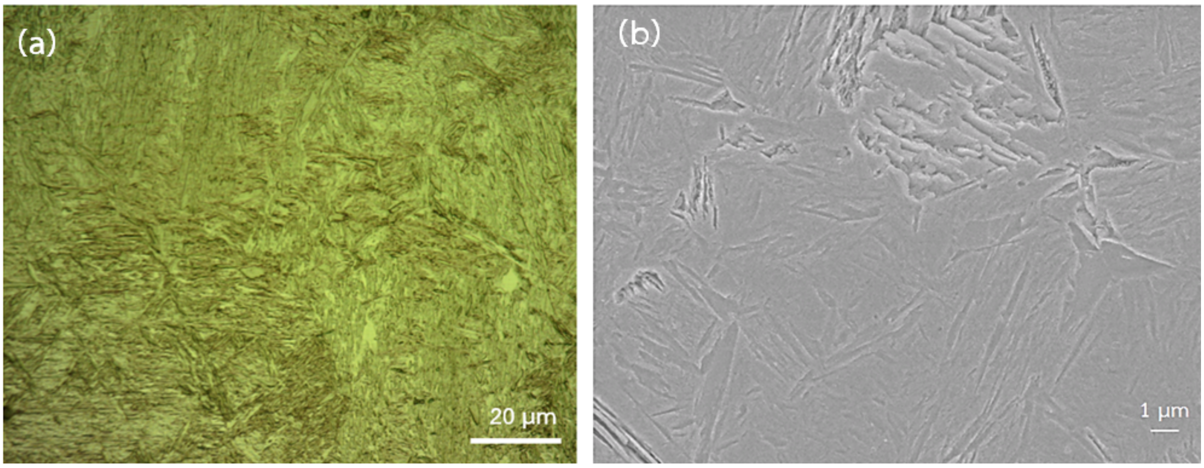

Fig. 3 Micrographs show the microstructure after hardening at 850 °C for 30 minutes by (a) optical microscopy and (b) scanning electron microscopy.

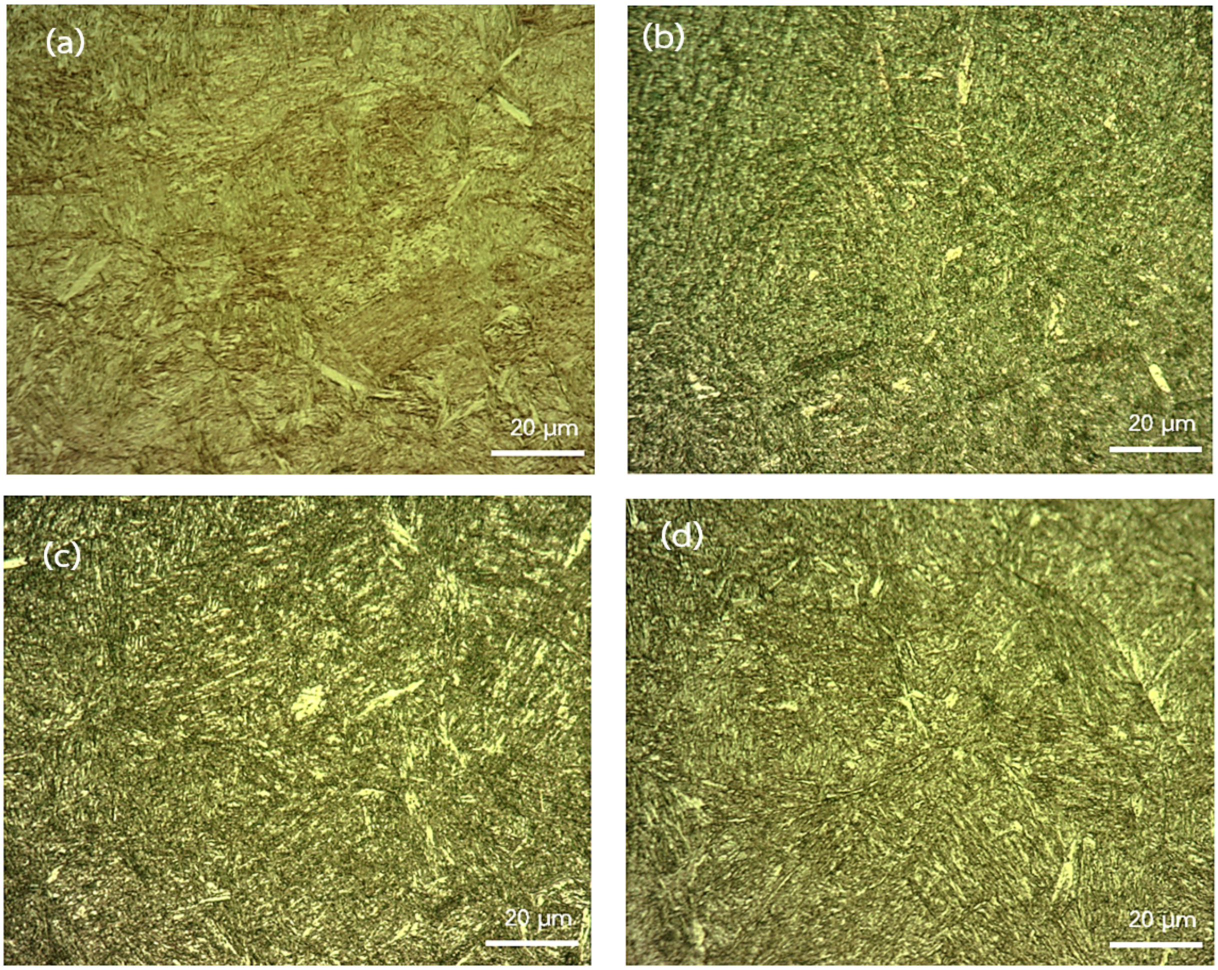

Fig. 4 Optical micrographs show the microstructure after hardening at 850 °C for 30 minutes follows by tempering at (a) 250 °C (b) 350 °C (c) 450 °C and (d) 550 °C for 30 minutes.

According to the microstructures after hardening at 850 °C for 30 minutes followed by tempering at 250, 350, 450 and 550 °C for 30 minutes which observed in Fig. 4(a), (b), (c) and (d), respectively, are similar to that of the hardened condition, except that some bainite sheaves are formed for each tempering temperatures that may form when austenite (the face centered cubic crystal structure of iron) is cooled past a critical temperature [8]. Moreover, the cementite precipitates and ferrite matrix are growths of the size after tempering temperature increases that shown in Fig. 4. In many bainitic microstructures, tempering even at higher temperatures as 550 °C has only a small effect on cementite size and morphology. An EDS analysis revealed that the phases present in 5160 steel after hardening and tempering treatment are containing C, Si, Cr, Mn, and Fe-rich phase as shown in Fig. 5. Each spectrum of the carbon element in Table 2 was increased after tempering temperature increased due to the coarsening of metallic elements phases. Consequently, it was according to a reported of S. Perla [9].

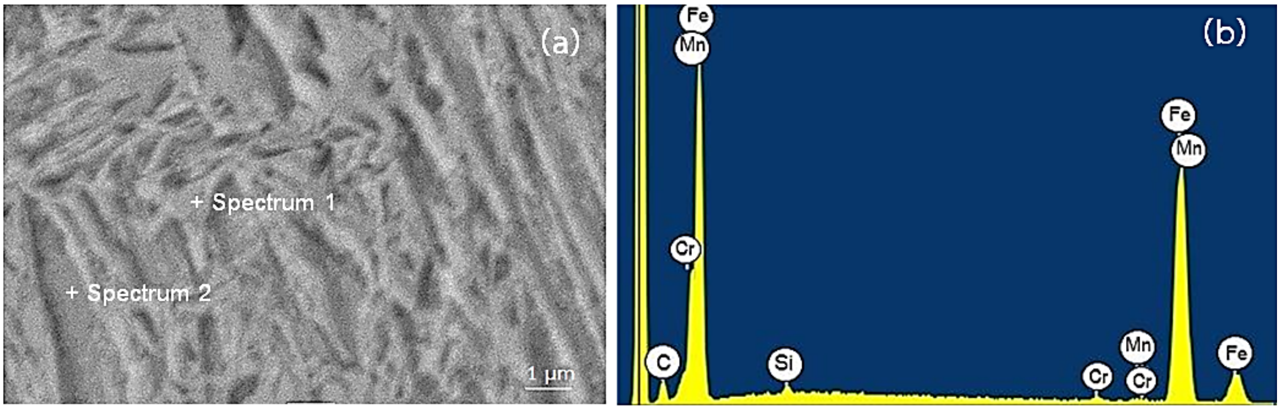

Fig. 5 (a) SEI shows the phases present and (b) EDS spectra after hardening and tempering.

Table 2 Element (weight %) of AISI 5160, under different heat treatment condition.

Heat treatment	**Spectrum**	**Element (weight %)**					
		C	Si	Cr	Mn	Fe	O
Hardened/850 °C for 30 minutes	1	4.82	0.41	0.75	0.74	93.28	–
	2	5.99	0.40	0.75	0.88	91.99	–
Hardened and tempering/	1	6.03	0.53	0.85	0.72	91.87	–
850 °C for 30 minutes → 250 °C for 30 minutes	2	5.47	0.49	0.78	0.75	92.52	–
Hardened and tempering/	1	8.37	–	0.080	0.93	86.92	2.98
850 °C for 30 minutes → 550 °C for 30 minutes	2	7.33	0.49	0.55	0.83	90.80	–

Hardness and tensile testing

Rockwell hardness for all heat treatment conditions are performed at room temperature and results are illustrated in Fig. 6. The hardening increased hardness compared to the as-sheet condition. Hardness in the as-sheet condition was about 40 HRC. Fig. 6 shows the hardness results after hardening at 850 –1050 °C for 30 – 120 minutes. It was found that the maximum hardness was about 62 HRC after hardening at 850 °C for 30 minutes, while the hardness was slightly decrease after higher temperatures and longer times.

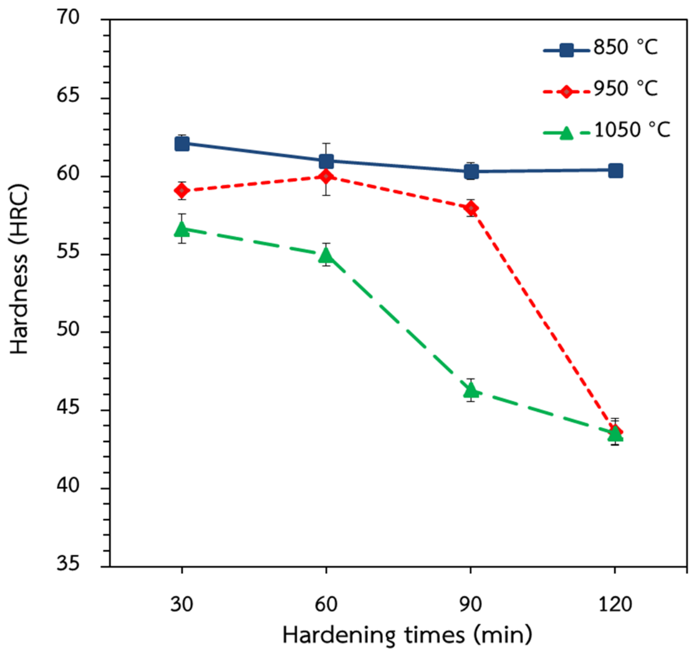

Fig. 6 Effect of hardening times on hardness after hardening for different temperatures and times.

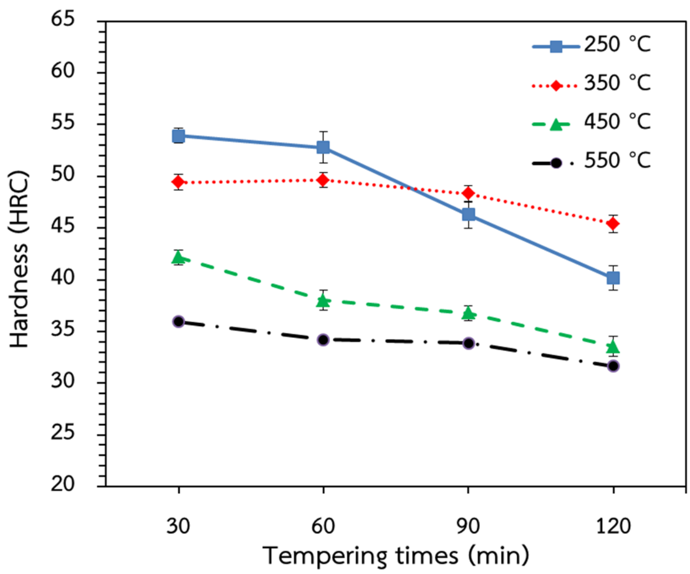

Fig. 7 Effect of tempering times on hardness after hardening at 850 °C for 30 minutes followed by tempering for different temperatures and times.

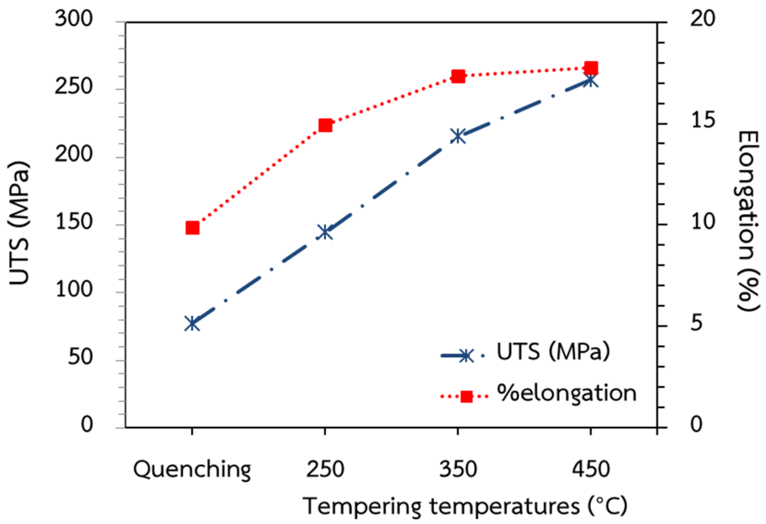

Fig. 8 Effect of hardening and tempering on ultimate tensile strength and %elongation after hardening at 850 °C for 30 minutes and hardening at 850 °C for 30 minutes followed by tempering at different temperatures for 30 minutes.

Effects of tempering times on hardness of hardening at 850 °C for 30 minutes followed by tempering at different temperatures and times are shown in Fig. 7, the hardness of each heat treatment were steadily decreased by increasing tempering time and temperature. Due to the structural point of view, retained austenite transforms to bainite, which according to the resultant microstructures are coarsening and spheroidisation of cementite along with recovery and recrystallization of ferrite [1]. Coarsening eventually causes a decrease in hardness at high tempering temperatures due to cementite precipitates at the expense of carbon in solid solution, but the ultimate tensile strength and %elongation begins to increased due to the process reduced brittleness by plastic deformation and ductile fracture.

4. Conclusion

The microstructure in the as-sheet condition consisted of ferrite and pearlite. After hardened are observed martensite late and plate and a small amount of retained austenite. Tempered martensite was occurred after hardening followed by tempering treatment.

Peak hardness was obtained after hardening at 850 °C for 30 minutes at 62 HRC. As the tempering temperatures increase the hardness of 5160 steel was slightly decreased while gradually increased ultimate tensile strength and %elongation.

5. Suggestions

As a result of the investigation conducted in this research, it was apparent that this work would serve as a good stepping stone for future work. Test the application of this model to other steel alloys. This could be in the form of an elemental study in which the effect of varying alloying additions to plain carbon steels is evaluated.

6. Acknowledgement

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