Table1. Chemical composition of the ilmenite concentrate as pure oxides (wt%)

Compositions	TiO_2	FeO	Fe_2O_3	SiO_2	MnO	MgO	CaO	V_2O_5	Al_2O_3	P_2O_5	S
Content	45.73	32.41	17.09	2.68	0.78	0.59	0.26	0.198	0.163	0.094	<0.005

Table 2 Control model and kinetic parameter at different addition of Na_2CO_3

Na_2CO_3 additive	Control link	Kinetic models	G(α)	Ea (kJ/ mol)
0%	Interfacial chemical reaction control	Three-dimensional phase boundary reaction	$1-(1-\alpha)^{1/3}=kt$	105.01
3%	Mixed control of interfacial chemical reaction and diffusion	First-order reaction (Mample) Three-dimensional diffusion	$-ln(1-\alpha)=kt$ $(1-2/3\alpha)-(1-\alpha)^{2/3}=kt$	112.07
6%	Diffusion control	Three-dimensional diffusion	$[1-(1-\alpha)^{1/3}]^2=kt$	123.48

Table 3. Comparison of apparent activation energies from this research with those of previous researches

Raw materials	T (K)	Ea(kJ/mol)	Reference
Bama ilmenite concentrate, graphite	1123-1373	265	Wang et al.[19]
Ilmenite concentrate, charcoal	1273-1473	135	El-Tawil et al. [37]
Bama ilmenite concentrate, graphite	1373-1523	164	Wang et al.[19]
Ilmenite concentrate, graphite	1373-1573	105.01	This study
Bama ilmenite concentrate, graphite	1523-1673	157	Wang et al.[19]
Panzhihua ilmenite concentrate, graphite	1573-1773	219.2	Gou et al.[18]
Ilmenite concentrate with 3% Na_2CO_3, graphite	1373-1573	112.07	This study
Ilmenite concentrate with 6% Na_2CO_3, graphite	1373-1573	123.48	This study
Ilmenite concentrate with 30% Na_2CO_3, charcoal	1273-1473	67	El-Tawil et al. [9]

Table 4. Comparison of chemical composition of the raw material from this research with those of previous researches (wt%)

Reference	TiO_2	FeO	Fe_2O_3	SiO_2	MnO	MgO	CaO	Al_2O_3	Main phase
This study	45.73	32.41	17.09	2.68	0.78	0.59	0.26	0.16	$FeO·TiO_2$, Fe_2O_3
El-Tawil et al. [37]	42	24.79	28.81	2.98	0.16	-	-	-	$FeO·TiO_2$, Fe_2O_3
Wang et al. [19]	49.78	24.33	12.94	5.26	1.24	0.16	0.16	3.18	$FeO·TiO_2$, $Fe_2O_3·3TiO_2$
Gou et al. [18]	43.68	39.30	-	3.15	0.39	7.99	1.28	2.91	$FeO·TiO_2$